$$C-QUIET5 = X_k^n = X_k = \{0, 0 \le k \le 256$$

The duration of C-QUIET5, $L_{C\text{-}QUIET5}$, is equal to 512 symbols. C-REVERB3 follows C-QUIET5.

12.4.8. C-REVERB3

C-REVERB3 is a signal that allows the ATU-R receiver to perform synchronization and to train any receiver equalizer. C-REVERB3 is the same signal as C-REVERB2 (see Section 12.4.6). The length of C-REVERB3, $L_{C\text{-}REVERB2}$, is equal to 1024 (repeating) symbols without cyclic prefix. This is the last segment of transceiver training and C-SEGUE1 follows immediately after C-REVERB3.

12.5. Transceiver Training (ATU-R)

As a timeout feature throughout initialization, no states in Transceiver Training is allowed to be resided in continuously for more than 8000 symbols. If that occurs, the ATU-R will reset to R-QUIET1.

12.5.1. R-QUIET2

R-QUIET2 is a silent signal that is defined as

$$R-QUIET2 = X_k^n = X_k = \{0, 0 \le k \le 32$$

The duration of R-QUIET2, $L_{R\text{-}QUIET2}$, is equal to 128 DMT symbols. R-REVERB1 follows R-QUIET2 as soon as ATU-R receiver ceases to detect C-REVEILLE signal.

12.5.2. R-REVERB1

R-REVERB1 is used to train the receiver AGC at ATU-C. R-REVERB1 is based on the psuedo-random binary sequence (PRBS) generated by the primitive polynomial,

$$p(D) = 1 + D^5 + D^6$$

with initial condition = 111111. We apply the PRBS to each sub-carrier, X_k, k=0 to k=32 in succession. We group D.C. (k=0) and Nyquist (k=32) together for encoding the signal and treat them as the first sub-carrier. Thus if we define the bit stream out of the PRBS generator as:

$p_1 p_2 p_3 p_4 p_5 p_6$..... ,
then the first (odd) bit of each pair of bits determines the polarity of the imaginary part of the sub-carrier and the second (even) bit determines the polarity of the real part. Specificially,

(p_{2k}, p_{2k-1})	Constellation (real, imaginary)
(0,0)	(+,+)
(0,1)	(+,-)
(1,0)	(-,+)
(1,1)	(-,-)

Table 12.5.1 Mapping to 4 QAM signal constellation

where p_1 maps to Nyquist, p_2 maps to D.C., (p_4, p_3) maps to sub-carrier 1 (k=1), and so on. The signal level is chosen to conform with any appropriate power mask. The pilot carrier (tone #16 at 69 kHz) is overwritten by (+,+) signal constellation with appropriate signal level.

R-REVERB1 is a periodic signal, without cyclic prefix, that is transmitted consecutively for 4096 symbols. The first 512 symbols coincides with C-QUIET3 signal in time, the second 512 symbols coincides with C-REVERB1, and the last 3072 symbols coincides with C-QUIET4. R-QUIET3 follows immediately after R-REVERB1.

12.5.3. R-QUIET3

R-QUIET3 is a silent signal that is defined as

$$R-QUIET3 = X_k^n = X_k = \{0, 0 \le k \le 32$$

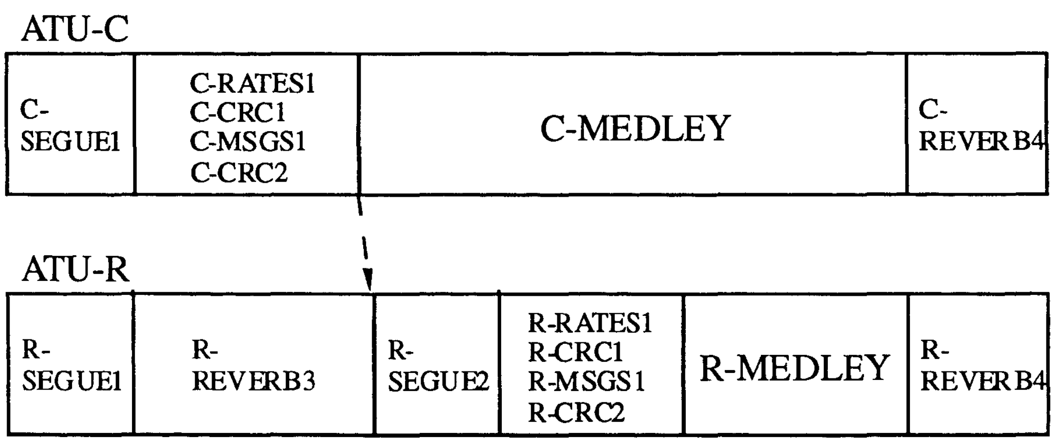
$L_{R\text{-}QUIET3}$ = 2048 symbols, of which the first 512 symbols coincides with C-ECT in time, and the next 1536 symbols coincides with C-REVERB2. R-ECT follows immediately after R-QUIET-3.

12.5.4. R-ECT

R-ECT, similar to C-ECT, is a vendor-defined signal that is intended to train the echo canceller at ATU-R for EC versions. Vendors of FDM versions have absolute freedom to define R-ECT signal. However, the length of R-ECT, $L_{R\text{-}ECT}$, is fixed at 512 DMT symbols. The receiver at ATU-C ignores this signal. R-REVERB2 follows R-ECT.

12.5.5. R-REVERB2

The signal R-REVERB2 is identical to R-REVERB1 (see Section 12.5.2). This signal can be used by ATU-C to perform timing recovery and receiver equalizer training. The length of R-REVERB2, $L_{R\text{-}REVERB2}$, is equal to 1024 symbols. This signal is the last segment of Transceiver Training. ATU-R then begins channel anaylsis and starts transmitting R-SEGUE1.



(Drawn Not to Scale)

Figure 12.1.4 Timing Diagram of Channel Analysis (12.6-12.7)

12.6. Channel Analysis (ATU-C)

Starting from this section onward, there are two cases where the ATU-C will reset itself to C-ACT1 (or C-ACT2). The first case is the timeout feature that limits the maximum consecutive stays at each state to be no more than 17000 symbols; otherwise, the ATU-C will reset to C-ACT1 (or C-ACT2). The second case is the CRC checksum:

if the CRC checksum indicates there is an error of the receive signal, then it will trigger a reset to C-ACT1 (or C-ACT2).

12.6.1. C-SEGUE1

Except for the pilot tone, C-SEGUE1 is generated from a tone-by-tone 180 degree phase reversal of C-REVERB1 (i.e. + maps to -, and - maps to +, for each of the 4-QAM signal constellation). The duration of C-SEGUE1 is $L_{C\text{-}SEGUE1}$ = 2 (repeating) symbol periods. Following C-SEGUE1, ATU-C enters state C-RATES1.

12.6.2. C-RATES1

C–RATES1 is the first ATU-C signal for which a cyclic prefix is used. The purpose of C–RATES1 is to transmit four options of data rates and formats to the ATU-R. Each option consists of three fields: B_F, B_I, and P_FP_ISI. B_F, which lists the number of bytes in the fast buffer for each of AS0, AS1, AS2, AS3, LS0, LS1, LS2, LS0 (upstream), LS1 (upstream), LS2 (upstream) channels, in that order, has a total of 10 times 8 = 80 bits. The first 8-bit of B_F specifies the number of bytes in AS0, the second 8-bit of B_F specifies the number of bytes in AS1, and so on. Each byte of B_F is transmitted with LSB first. Similarly, B_I specifies the number of bytes in the interleave buffer for each of AS0, AS1, AS2, AS3, LS0, LS1, LS2, LS0 (upstream), LS1 (upstream), LS2 (upstream) channels. P_FP_ISI is an eight-byte quantity: the number of parity bytes per symbol in the fast buffer (downstream) P_F, the number of parity bytes per symbol in the interleave buffer (downstream) P_I, the number of symbols per codeword (downstream) S, the interleave depth (downstream) I in codewords for the interleave buffer, and the same four quantity P_FP_ISI in the upstream direction (one-byte each, in that order). The four options are transmitted in order of decreasing preference. Figure 12.6.1 summaries C-RATES1 as well as R-RATES1 (see Section 12.7.2).

Only one bit of information is transmitted during each symbol period of C–RATES1: a zero bit is encoded to one symbol of C-REVERB1 and a one bit is encoded to one symbol of C-SEGUE1. Since there are a total of 896 bits of RATES1 information, the length of C-RATES1, $L_{C\text{–}RATES1}$, is equal to 896 symbols. The 896 bits are to be transmitted in the order shown in Figure 12.6.1, with the least significant bit first. In other words, the least significant bit of Option 1 B_F, is to be transmitted during the first symbol of C–RATES1. Following C–RATES1, the ATU-C should enter signaling state C–CRC1.

12.6.3. C-CRC1

C–CRC1 is a cyclic redundancy code intended for detection of an error in the reception of C–RATES1 at the ATU-R. Consider the 896 bits of information contained in C–RATES1 and shown in Figure 12.6.1. Denote the 896 bits in Figure 12.6.1 as $\{a_0, a_1 \ldots a_{895}\}$, with a_0, the least significant bit of Option 1 B_F . Then define the polynomial a(D) as

$$a(D) = a_0\, D^{895} + a_1\, D^{894} + \ldots + a_{895}$$

and the CRC generator polynomial g(D) as

$$g(D) = D^{16} + D^{12} + D^5 + 1$$

Denote the 16 bits to be communicated during C–CRC1 as $\{c_0, c_1, \ldots c_{15}\}$; then the corresponding polynomial

$$c(D) = c_0 D^{15} + c_1 D^{14} + \ldots + c_{14} D + 1$$

is the remainder of a(D)D^{16} divided by g(D). The 16 bits c_0 - c_{15} are transmitted (c_0 first and c_{15} last) in $L_{C\text{–}CRC1}$ = 16 symbol periods using the same method as described in Section 12.6.2). Following C–CRC1, the ATU-C should enter signaling state C–MSGS1.

12.6.4. C-MSGS1

C–MSGS1 transmits a 32-bit message signal to the ATU-R. This message would include vendor identification, ATU-C transmit power level used, trellis code option, echo canceller option, and so on. The specific valid messages

and their encoding into 32-bit words are TBD. A total of $L_{C-MSGS1}$ = 32 symbol periods are used to communicate the 32 bit message, using the same encoding method as described in Section 12.6.2. Following C–MSGS1, the ATU-C should enter signaling state C–CRC2.

12.6.5. C-CRC2

C–CRC2 is a cyclic redundancy code intended for detection of an error in the reception of C–MSGS1 at the ATU-R. The CRC polynomial is generated in exactly the same way as defined in Section 12.6.3. These 16 bits are transmitted in L_{C-CRC2} = 16 symbol periods using the method described in Section 12.6.2. Following C–CRC2, the ATU-C should enter signaling state C–MEDLEY.

12.6.6. C-MEDLEY

C–MEDLEY is a wideband pseudorandom signal used for estimation of the downstream SNR at the ATU-R. The data to be transmitted are derived from the pseudo-random sequence defined in Section 12.4.3, continuing from one symbol to the next. Since the PRBS sequence is of length 511, and 512 bits are used for each symbol, the sub-carrier vector for C–MEDLEY changes from one symbol period to the next. The pilot sub-carrier is over-written by the (+,+) signal constellation. C–MEDLEY is active for $L_{C-MEDLEY}$ = 16384 symbol periods. Following C–MEDLEY the ATU-C enters signaling state C–REVERB4.

12.6.7. C-REVERB4

C–REVERB4 is the same as C–REVERB2 (see Section 12.4.6), the only difference being the addition of cylic prefix on every symbol. The duration of C–REVERB4 is not fixed. After successful detection of R-SEGUE3 and reception of R-MSGS2, R-CRC3, R-RATES2, and R-CRC4, the ATU-C continues to transmit C-REVERB4 for another 80 symbols before entering state C–SEGUE2 (see Section 12.8.1).

12.7. Channel Analysis (ATU-R)

Starting from this section onward, there are two cases where the ATU-R will reset itself to R-QUIET1. The first case is the timeout feature that limits the maximum consecutive stays at each state to be no more than 17000 symbols; otherwise, the ATU-R will reset to R-QUIET1. The second case is the CRC checksum: if the CRC checksum indicates there is an error of the receive signal, then it will trigger a reset to R-QUIET1.

12.7.1. R-SEGUE1

Except for the pilot tone, R–SEGUE1 is generated from a tone-by-tone 180 degree phase reversal of R-REVERB1 (i.e. + maps to -, and - maps to +, for each of the 4-QAM signal constellation). The duration of R–SEGUE1 is $L_{R-SEGUE1}$ = 2 symbol periods. Following R-SEGUE1 the ATU-R enters state R-REVERB3.

12.7.2. R-REVERB3

R–REVERB3 is the same as R–REVERB1 (see Section 12.5.2), the only difference being the addition of cylic prefix on every symbol. The duration of R-REVERB3, $L_{R-REVERB3}$, is not fixed. Upon a successive detection of C-SEGUE1 and reception of C-RATES1 through C-CRC2, the ATU-R continues to send R-REVERB3 for 20 additional symbols before entering R-SEGUE2.

12.7.3. R-SEGUE2

The sub-carrier sequence that generates R–SEGUE2 is identical to that for R-SEGUE1 (see Section 12.7.1). The duration of R-SEGUE2 is $L_{R-SEGUE2}$ = 2 symbol periods. Following R-SEGUE2 the ATU-R enters state R-RATES1.

12.7.4. R-RATES1

The purpose of R-RATES1 is similar to that of C-RATES1, except this is only for the upstream direction (see Section 12.6.2). Each option consists of three fields: B_F, B_I, and P_FP_ISI. B_F, which lists the number of bytes in the fast buffer for each of LS0, LS1, LS2 channels, in that order, has a total of 3 times 8 = 24 bits. The first 8-bit

of B_F specifies the number of bytes in LS0, the second 8-bit of B_F specifies the number of bytes in LS1, and so on. Each byte of B_F is transmitted with LSB first. Similarly, B_I specifies the number of bytes in the interleave buffer for each of LS0, LS1, LS2 channels. $P_F P_I SI$ is a four-byte quantity: the number of parity bytes per symbol in the fast buffer (upstream) P_F, the number of parity bytes per symbol in the interleave buffer (upstream) P_I, the number of symbols per codeword (upstream) S, and the interleave depth (upstream) I in codewords for the interleave buffer (one-byte each, in that order). The four options are transmitted in order of decreasing preference. Figure 12.6.1 summaries R-RATES1 as well as C-RATES1 (see Section 12.6.2). For the present system, ATU-C has control over all the data rates, and so R-RATES1 is copied from the appropriate fields of C-RATES1.

Only one bit of information is transmitted during each symbol period of R–RATES1: a zero bit is encoded to one symbol of R-REVERB1 and an one bit is encoded to one symbol of R-SEGUE1. Since there are a total of 320 bits of RATES1 information, the length of R-RATES1, $L_{R-RATES1}$, is equal to 320 symbols. The 320 bits are to be transmitted in the order shown in Figure 12.6.1, with the least significant bit first. In other words, the least significant bit of Option 1 B_F, is to be transmitted during the first symbol of R–RATES1. Following R–RATES1, the ATU-R should enter signaling state R–CRC1.

12.7.5. R-CRC1

R-CRC1 is a cyclic redundancy code intended for detection of an error in the reception of R-RATES1 at the ATU-C. The CRC polynomial c(D) is generated in exactly the same manner as C-CRC1 (see Section 12.6.3), with the same generator polynomial g(D). The 16 bits c_0 - c_{15} are transmitted (c_0 first and c_{15} last) in $L_{R\text{-}CRC1}$ = 16 symbol periods using the same method as R-RATES1 (see Section 12.7.4). Following R-CRC1, the ATU-R should enter signaling state R-MSGS1.

12.7.6. R-MSGS1

R-MSGS1 transmits a 32-bit message signal to the ATU-C. This message would include vendor identification, trellis code option, echo canceller option, and so on. The specific valid messages and their encoding into 32-bit words are TBD. A total of $L_{R\text{-}MSGS1}$ = 32 symbol periods are used to transmit the 32 bit message, using the same method as transmitting R-RATES1 (see Section 12.7.4). Following R-MSGS1, the ATU-R should enter signaling state R-CRC2.

12.7.7. R-CRC2

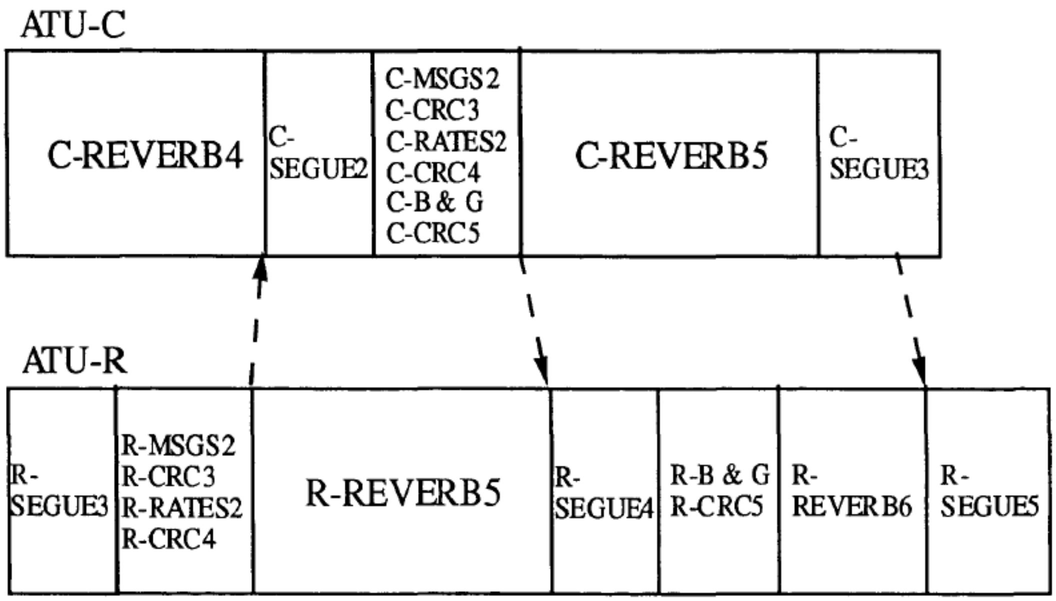
R-CRC2 is a cyclic redundancy code intended for detection of an error in the reception of R-MSGS1 at the ATU-C. The CRC polynomial is generated in exactly the same way as described in Section 12.6.3. These 16 bits are transmitted in $L_{R\text{-}CRC2}$ = 16 symbol periods using the method described in Section 12.7.4. Following R-CRC2, the ATU-R should enter signaling state R-MEDLEY.

12.7.8. R-MEDLEY

R-MEDLEY is a wideband pseudorandom signal used for estimation of the upstream SNR at the ATU-C. The data to be transmitted are derived from the pseudo-random sequence defined in Section 12.5.2, continuing from one symbol to the next. Since the sequence is of length 63, and 64 bits are used for each symbol, the sub-carrier vector for R-MEDLEY changes from one symbol period to the next. The pilot sub-carrier is over-written by the (+,+) signal constellation. R-MEDLEY is active for $L_{R\text{-}MEDLEY}$ = 16384 symbol periods. Following R-MEDLEY the ATU-R enters signaling state R-REVERB4.

12.7.9. R-REVERB4

R–REVERB4 is the same as R–REVERB3 (see Section 12.7.2). The duration of R-REVERB4 $L_{R-REVERB4}$, is equal to 128 symbols. This signal marks the end of channel analysis, and R-SEGUE3 immediately follows R–REVERB4.



(Drawn Not to Scale)

Figure 12.1.5 Timing Diagram of Exchange
(12.8-12.9)

12.8. Exchange (ATU-C)

Throughout this section, there are two cases where the ATU-C will reset itself to C-ACT1 (or C-ACT2). The first case is the timeout feature that limits the maximum consecutive stays at each state to be no more than 4000 symbols; otherwise, the ATU-C will reset to C-ACT1 (or C-ACT2). The second case is the CRC checksum: if the CRC checksum indicates there is an error of the receive signal, then it will trigger a reset to C-ACT1 (or C-ACT2).

12.8.1. C-SEGUE2

The sub-carrier sequence that generates C–SEGUE2 is identical to that for C–SEGUE1 (see Section 12.6.1). The duration of C–SEGUE-2 is $L_{C\text{–}SEGUE2} = 2$ symbol periods. Following C–SEGUE2 the ATU-C enters state C–MSGS2.

12.8.2. C-MSGS2

C–MSGS2 transmits a 32-bit message signal to the ATU-R. The specific valid messages and their encoding into 32-bit words are TBD. A total of $L_{C\text{–}MSGS2} = 4$ symbol periods are used to communicate the 32 bit message, with 8 bits transmitted on each symbol. Two bits are encoded onto each of the sub-carriers numbered 27 through 30 using the 4QAM constellation labeling shown in Table 12.4.1. The same two bits are also encoded in the same way onto a set of backup carriers, namely, sub-carriers 37 through 40. The least significant byte of the message is transmitted in the first symbol of C–MSGS2, with the two least significant bits of each byte encoded onto carriers 27 and 37. In addition, the pilot, sub-carrier 64, should be modulated with (+,+). Following C–MSGS2, the ATU-C should enter signaling state C–CRC3.

12.8.3. C-CRC3

C–CRC3 is a cyclic redundancy code intended for detection of an error in the reception of C–MSGS2 at the ATU-R. The CRC polynomial is generated in exactly the same way as defined in Section 12.6.3. These bits are transmitted

in $L_{C-CRC3} = 2$ symbol periods using the method described in Section 12.8.2. Following C–CRC3, the ATU-C should enter signaling state C–RATES2.

12.8.4. C-RATES2

C-RATES2 contains the same amount of information as R-RATES1 (see Section 12.7.2), since C-RATES2 is the reply for R-RATES1. In addition, C-RATES2 is also based on the compromise between R-RATES2 and the rates (SNR) result for the upstream direction available to ATU-C at this point. Unlike R-RATES1 that has four optins, C-RATES2 only has one option: the rates information that the ATU-R transmitter will be using during steady-state transmission (upstream data rate), and the rates information that the ATU-R receiver will be using during steady-state transmission (downstream data rate). Since we have already specified the B_F and B_I values for each of the ASs and LSs channels during C-RATES1 and R-RATES1, there is no need to repeat these information at this point. Instead, only the option number is sent back to the other end. For C-RATES2, since we assume that ATU-C has the final decision on the rates for both the downstream and upstream direction, C-RATES2 contains the option number for downstream as well as upstream direction. The length of C-RATES2 is equal to 8 bits, and the bit pattern for C-RATES2 is shown in Table 12.8.1. Other bit patterns that are not specified in the table are reserved for future use. If none of the options requested during C-RATES1 and R-RATES1 can be implemented, ATU-C then returns to C-ACT1 (or C-ACT2) for retraining. A total of $L_{C-RATES2} = 1$ symbol periods are used to transmit these 8 bits using the method described in Section 12.8.2. Following C–RATES2, the ATU-C should enter signaling state C–CRC4.

(Downstream, Upstream)	Bit Pattern for C-RATES2 (MSB first)[1]
(Option 1, Option 1)	00010001
(Option 1, Option 2)	00010010
(Option 1, Option 3)	00010100
(Option 1, Option 4)	00011000
(Option 2, Option 1)	00100001
(Option 2, Option 2)	00100010
(Option 2, Option 3)	00100100
(Option 2, Option 4)	00101000
(Option 3, Option 1)	01000001
(Option 3, Option 2)	01000010
(Option 3, Option 3)	01000100
(Option 3, Option 4)	01001000
(Option 4, Option 1)	10000001
(Option 4, Option 2)	10000010
(Option 4, Option 3)	10000100
(Option 4, Option 4)	10001000
All Options Fail [2]	00000000

Table 12.8.1 Bit Pattern for C-RATES2

12.8.5. C-CRC4

C–CRC4 is a cyclic redundancy code intended for detection of an error in the reception of C–RATES2 at the ATU-R. Its relation to C-RATES2 is the same as that of C-CRC3 to C-MSGS2. Following C–CRC4, the ATU-C should enter signaling state C–B&G.

12.8.6. C-B&G

The purpose of C–B&G is to transmit to the ATU-R the bits and gains information, $\{b_1, g_1, b_2, g_2, \ldots b_{31}, g_{31},\}$, to be used on the upstream carriers. b_i indicates the number of bits to be coded by the ATU-R transmitter

[1] All other bit patterns that are not shown are reserved for future use.

[2] After channel analysis, it is determined that none of the four options can be implemented with the connection. ATU-C then returns to C-ACT1 (or C-ACT2) for retraining.

onto the i th upstream carrier; g_i indicates the scale factor that should be applied to the i th upstream carrier, relative to the gain that was used for that carrier during the transmission of R–MEDLEY. b_0, g_0, b_{32}, and g_{32} are all presumed zero, meaning that no bits or energy will be transmitted at d.c. or one-half the sampling rate.

Each b_i is represented as an unsigned 4-bit integer, with valid b_i lying within the entire possible 4-bit range of zero to 15. Each g_i is represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 0100 0000 0000 would instruct the ATU-R to scale the constellation for carrier i, by a gain factor of 2, so that the power in that carrier should be 6 dB higher than it was during R–MEDLEY. A total of 62 bytes of bits and gains information is to be transmitted during C–B&G, and a total of $L_{C-B\&G}$ = 62 symbol periods is required, using the method described in Section 12.8.2. Following C–B&G the ATU-C enters signaling state C–CRC5.

12.8.7. C-CRC5

C–CRC5 is a cyclic redundancy code intended for detection of an error in the reception of C–B&G at the ATU-R. Its relation to C-B&G is the same as that of C-CRC3 to C-MSGS2. Following C–CRC5, the ATU-C should enter signaling state C–REVERB5.

12.8.8. C-REVERB5

The sub-carrier sequence that generates C–REVERB5 is the same as that for C–REVERB4 (see Section 12.6.7). The duration of C–REVERB5, $L_{C-REVERB5}$, depends upon the signaling state of the ATU-R and the internal processing of the ATU-C. The ATU-C should transmit C–REVERB5 until it has received and checked the reliability of the downstream bits and gains information contained in R–B&G. The ATU-C continues transmitting C–REVERB5 while these bits and gains parameters are established in the ATU-C transmitter. When the ATU-C is prepared to transmit according to the conditions specified in R–B&G, the ATU-C enters signaling state C–SEGUE3. At present, upon successful reception of R-CRC5, the ATU-C continues to transmit C-REVERB5 for another 32 symbols before entering C-SEGUE3.

12.8.9. C-SEGUE3

The purpose of C–SEGUE3 is to notify the ATU-R that the ATU-C is about to enter the steady-state signaling state C–SHOWTIME. The sub-carrier sequence that generates C–SEGUE3 is the same as that for C–SEGUE1 (see Section 12.6.1). The duration of C–SEGUE3 is $L_{C-SEGUE3}$ = 2 symbol period. Following C–SEGUE3 the ATU-C has completed initialization and enters state C–SHOWTIME.

12.9. Exchange (ATU-R)

12.9.1. R-SEGUE3

The sub-carrier sequence that generates R–SEGUE3 is identical to that for R-SEGUE1 (see Section 12.7.1). The duration of R-SEGUE3 is $L_{R-SEGUE3}$ = 2 symbol periods. Following R-SEGUE3 the ATU-R enters state R-MSGS2.

12.9.2. R-MSGS2

R-MSGS2 transmits a 32-bit message signal to the ATU-C. The specific valid messages and their encoding into 32-bit words are TBD. A total of $L_{R-MSGS2}$ = 4 symbol periods are used to transmit the 32 bit message, with 8 bits transmitted each symbol. Two bits are encoded onto each of the sub-carriers numbered 6 through 9, similar to C-MSGS2 (see Section 12.8.2). The same two bits are also encoded in the same way onto a set of backup carriers, namely, sub-carriers 10 through 13. The least significant byte of the message is transmitted in the first symbol of R-MSGS2, with the two least significant bits of each byte encoded onto carriers 4 and 10. In addition, the pilot, sub-carrier 16, should be modulated with (+,+). Following R-MSGS2, the ATU-R should enter signaling state R-CRC3.

12.9.3. R-CRC3

R-CRC3 is a cyclic redundancy code intended for detection of an error in the reception of R-MSGS2 at the ATU-C. The CRC polynomial is generated in exactly the same way as described in Section 12.6.3. These bits are transmitted in $L_{R\text{-}CRC3} = 2$ symbol periods using the method described in Section 12.9.2. Following R-CRC3, the ATU-R should enter signaling state R-RATES2.

12.9.4. R-RATES2

R-RATES2 contains the result of the C-RATES1 information. Instead of listing the B_F, B_I as in C-RATES1, we send back the option number that the ATU-R calculates based on the SNR of the downstream direction. Similar to C-RATES2, 4 bits are used for the option number. A total of 8 bits are used for R-RATES2, and the bit patterns are shown in Table 12.9.1. Other bit patterns that are not specified in the table are reserved for future use. If none of the options requested during C-RATES1 can be implemented, ATU-R then returns to R-QUIET1 for retraining. A total of $L_{R\text{-}RATES2} = 1$ symbol period is used to transmit these 8 bits using the method described in Section 12.9.2. Following R-RATES2, the ATU-R should enter signaling state R-CRC4.

Downstream	Bit Pattern for R-RATES2 (MSB first)[3]
Option 1	00010001
Option 2	00100010
Option 3	01000100
Option 4	10001000
All Options Fail[4]	00000000

Table 12.9.1 Bit Pattern for R-RATES2

12.9.5. R-CRC4

R-CRC4 is a cyclic redundancy code intended for detection of an error in the reception of R-RATES2 at the ATU-C. Its relation to R-RATES2 is the same as that of R-CRC3 to R-MSGS2. Following R-CRC4, the ATU-R should enter signaling state R-REVERB5.

12.9.6. R-REVERB5

R-REVERB5 is the same as R-REVERB3 (see Section 12.7.2). The duration of R-REVERB5, $L_{R\text{-}REVERB5}$, depends upon the signaling state of the ATU-C and the internal processing of the ATU-R. The ATU-R should transmit R-REVERB5 until it has received and checked the reliability of the upstream bits and gains information contained in C–B&G. After the ATU-R received C-CRC5, it continues to transmit R-REVERB5 for another 64 symbols. The ATU-R then enters R–SEGUE4.

12.9.7. R-SEGUE4

The purpose of R-SEGUE4 is to notify the ATU-C that the ATU-R is about to enter R-B&G. R-SEGUE4 is identical to R-SEGUE3 (see Section 12.9.1). The duration of R-SEGUE4 is $L_{R\text{-}SEGUE4} = 2$ symbol periods. Following R-SEGUE4 the ATU-R enters state R-B&G.

12.9.8. R-B&G

The purpose of R-B&G is to transmit to the ATU-C the bits and gains information, $\{b_1, g_1, b_2, g_2, \ldots\ldots b_{255}, g_{255}\}$, to be used on the downstream carriers. b_i indicates the number of bits to be coded by the ATU-C transmitter onto the i th downstream carrier; g_i indicates the scale factor that should be applied to the i th downstream carrier, relative to the gain that was used for that carrier during the transmission of C–MEDLEY. b_0, g_0, b_{256}, and g_{256} are all presumed zero, meaning that no bits or energy will be transmitted at DC or one-half the sampling rate.

---

[3] All other bit patterns that are not shown are reserved for future use.

[4] After channel analysis, it is determined that none of the four options can be implemented with the connection. ATU-R then returns to R-QUIET1 for retraining.

Each b_i is represented as an unsigned 4-bit integer, with valid b_i lying within the entire possible 4-bit range of zero to 15. Each g_i is represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 0100 0000 0000 would instruct the ATU-C to scale the constellation for carrier i by a gain factor of 2, so that the power in that carrier should be 6 dB higher than it was during C–MEDLEY. A total of 510 bytes of bits and gains information is to be transmitted during R-B&G, so that a total of $L_{R\text{-}B\&G} = 510$ symbol periods is required. The transmission format is the same as described in Section 12.9.2. Following R-B&G the ATU-R enters signaling state R-CRC5.

12.9.9. R-CRC5

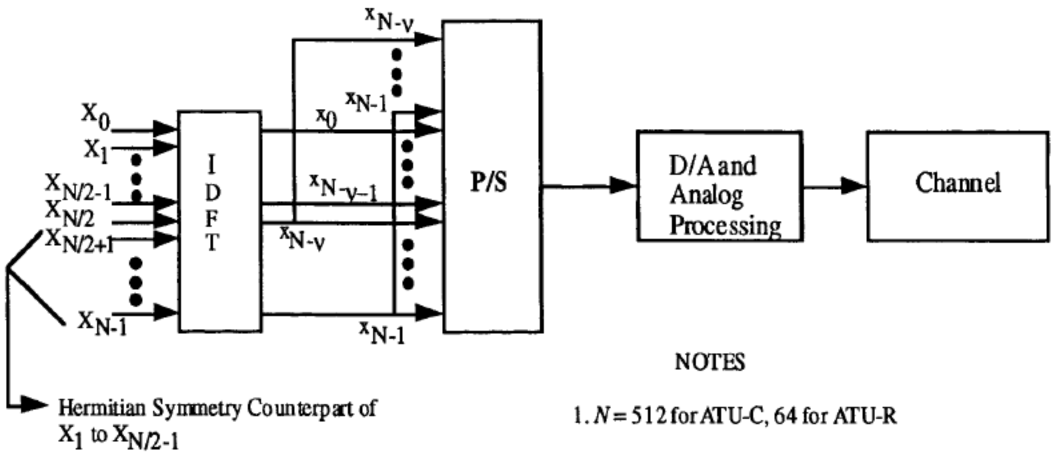
R-CRC5 is a cyclic redundancy code intended for detection of an error in the reception of R-B&G at the ATU-C. Its relation to R-B&G is the same as that of R-CRC3 to R-MSGS2. Following R-CRC5, the ATU-R should enter signaling state R-REVERB6.

12.9.10. R-REVERB6

R-REVERB6 is the same as R-REVERB3 (see Section 12.7.2). The duration of R-REVERB6, $L_{R\text{-}REVERB6}$, depends upon the signaling state of the ATU-C and the internal processing of the ATU-R. The ATU-R enters R–SEGUE5 when it detects that ATU-C has transmitted C-SEGUE3.

12.9.11. R-SEGUE5

The purpose of R-SEGUE5 is to notify the ATU-C that the ATU-R is about to enter the steady-state signaling state R-SHOWTIME. R-SEGUE5 is identical to R-SEGUE3 (see Section 12.9.1). The duration of R-SEGUE5 is $L_{R\text{-}SEGUE5} = 2$ symbol period. Following R-SEGUE5 the ATU-R has completed initialization and enters state R-SHOWTIME.



NOTES

1. N = 512 for ATU-C, 64 for ATU-R

2. ν = 32 for ATU-C with c-p
   4 for ATU-R with c-p
   0 with no c-p

3. X_k = DMT sub-carrier k

4. x_k = kth D/A input sample

Figure 12.1.6 Reference Model for DMT Transmitter

C-RATES1	Option 1			Option 2			Option 3			Option 4		
	B_F	B_I	PPSI	B_F	B_I	PPSI	B_F	B_I	PPSI	B_F	B_I	PPSI
Number of Bytes	10	10	8	10	10	8	10	10	8	10	10	8

R-RATES1	Option 1			Option 2			Option 3			Option 4		
	B_F	B_I	PPSI	B_F	B_I	PPSI	B_F	B_I	PPSI	B_F	B_I	PPSI
Number of Bytes	3	3	4	3	3	4	3	3	4	3	3	4

(Drawn Not to Scale)

Figure 12.6.1. C-RATES1 and R-RATES1 (12.6.2 and12.7.2)

13 On-line adaptation and reconfiguration

*********EDITORIAL NOTE*********

Sub-clause 13.1
Status : Under Study (August 23/93 Mtg.)
Cont. 93-252
Source: Amati

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Prov. Agree

13.1 Bit Swapping

Bit Swapping is a method by which the ADSL system can alter the number of bits assigned to a subcarrier or alter the transmitted energy of a subcarrier without interrupting data flow.

Bit swap takes place between a receiver and a transmitter. The receiver, which can be an ATU-C or an ATU-R, takes in the signal to be bit swapped from the U interface. The transmitter, which can be an ATU-R or an ATU-C, respectively, sends the signal to be bit swapped onto the U interface.

13.1.1 Bit Swap Channel

The bit swap channel uses the aoc channel which is described in Section 6.2. All bit swap messages are repeated five consecutive times over this channel. Note that according to section TBD, the aoc channel sends all binary zero's in idle mode.

13.1.2 Symbol Counting

After initialization is completed, both the transmitter and the receiver will start a 8 bit counter. This counter will allow coordination of the bit swap operation as described in the steps below. The transmitter will increment its counter each time after sending an ADSL superframe, and the receiver will increment its counter after receiving an ADSL superframe. The ADSL superframe is described in section 6.2 of the draft standard. The transmitter shall begin the counter just after transmitting the specific symbol described in section 11.9.8 of the draft standard. The receiver shall begin the counter just after receiving this symbol.

Resynchronization of this symbol counter is accomplished using the superframe counter in the ADSL frame structure as described in section TBD.

13.1.3 Bit Swap Request

The receiver will initiate a bit swap by sending a bit swap request back to the transmitter via the aoc channel. This request tells the transmitter what subcarriers are to be modified. The bit swap request message contains the following:

(A) Message header: consists of 12 binary ones.

(B) Message fields 1 through 4: Each of these message fields consist of a four-bit command followed by a related eight-bit subchannel index. The four bit commands can take on the values shown in Table 13.1-1. The eight bit subchannel index is counted from low to high frequencies with the lowest frequency subcarrier having the number zero.

Since a single bit subcarrier is not allowed, two message fields will be required to decrease the number of bits assigned to a two-bit subcarrier. Similarly, two message fields will be required to increase the number bits assigned to a zero-bit subcarrier.

The bit swap request is transmitted five consecutive times.

Value	Interpretation
0000	Do nothing
0001	Increase the allocated number of bits by one.
0010	Decrease the allocated number of bits by one.
0011	Change the transmitted power by the factor g1 (TBD)
0100	Change the transmitted power by the factor g2 (TBD)
0101	Change the transmitted power by the factor g3 (TBD)
0110	Change the transmitted power by the factor g4 (TBD)
0111	Change the transmitted power by the factor g5 (TBD)

Table 13.1-1 Bit Swap Request Commands

13.1.4 Bit Swap Acknowledge

The transmitter will act on a bit swap request when it has received three identical bit swap request messages. The transmitter will then send a bit swap acknowledge. The bit swap acknowledge message contains the following:

(A) A message header containing twelve binary ones.

(B) The symbol number when the bit swap is to take place. This part of the message contains four zero's, followed by 8 bits containing the symbol number.

The bit swap acknowledge is transmitted five consecutive times.

13.1.5 Bit Swap (Receiver)

The receiver will act on a bit swap request when it has received three identical bit swap acknowledge messages. The receiver will then wait until the symbol counter equals the value specified in the bit swap acknowledge. When this occurs, the receiver will do the following:

(A) Change the bit assignment of the appropriate subcarriers.

(B) Make adjustments to the appropriate subcarriers to account for a change in their transmitted energy.

13.1.6 Bit Swap (Transmitter)

After transmitting the bit swap acknowledge, the transmitter will wait until the symbol counter equals the value specified in the bit swap acknowledge. When this symbol occurs, the transmitter will do the following:

(A) Change the bit assignment of the appropriate subcarriers.

(B) Change the transmitted energy in the appropriate subcarriers by the desired factor.

13.2 Changes to data rates and reconfiguration

TBD

***********EDITORIAL NOTE***********
Clause 14
Status : Under Study (August 23/93 Mtg.)
Cont. 93-215
Source: NT
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14 Signaling requirements

ADSL supports both Simplex and Duplex bearer channels in a variety of configurations (see 5.1).

Bearer service is defined as the end-end service, for example 1.536 Mbit/s unrestricted digital information, which is selected and is carried over a particular bearer channel on an ADSL loop. ADSL bearer channels may support a variety of bearer services. These bearer services are for further study.

Two methods of signaling protocols for controling bearer service are recognized for ADSL:

1) In-band signaling
In-band signaling is defined as a signaling protocol controling a bearer service carried over an ADSL bearer channel, where the signaling protocol is within the same ADSL bearer channel as the bearer service.
For example, a data protocol stack, such as TCP/IP or OSI, may employ network layer and higher layer signaling protocols within a bearer service transported over ADSL. In-band signaling protocols are carried transparently: not affected nor interpreted by the ADSL system.

2) Out-of-band signaling
Out-of-band signaling is defined as a signaling protocol controling a bearer service carried over an ADSL bearer channel, where the signaling protocol is carried in a different ADSL bearer channel than the bearer service. In this case, the ADSL C channel shall be used to carry the signaling protocol.

Signaling protocols for in-band and out-of-band signaling are for further study.

Note: when the LS1 Duplex channel is used to carry an ISDN BRA (2B+D+overhead) payload, the ISDN BRA multiplex is carried transparently: for the ISDN bearer services carried on the BRA, the signalling is within the BRA D channel and is not affected nor interpreted by the ADSL system.

15 Loop plant, impairments, and testing (under study)

15.1 Test loops (under study)

15.2 Impairments and simulation in testing (under study)

15.3 Test procedures (under study)

15.4 Performance test requirements (under study)

16 Physical characteristics

*********EDITORIAL NOTE*********

Clause 16
Status : Under Study (August 23/93 Mtg.)
Cont. 93-216
Source: NT

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16.1 Wiring polarity integrity

The POTS and ATU-R shall not be dependent on a specific polarity for the two wires of the access line as the pair may be reversed.

16.2 Connector

Specification of the plug and jack arrangement at the network interface is under study.

*********EDITORIAL NOTE*********

Clause 17
Status : Under Study (August 23/93 Mtg.)
Cont. 93-217
Source: NT

Pill Agreed **

17 Environmental conditions

17.1 Protection

Material referring to protection may be found in annex E of this standard.

17.2 Electromagnetic compatibility

Material referring to electromagnetic compatibility may be found in annex E of this standard.

*********EDITORIAL NOTE*********

Annex A
Status : Under Study
Cont. - NEW PROPOSED ANNEX
Source: Amati
NOTE:
This is the first time this annex has been proposed (November 15, 1993) .
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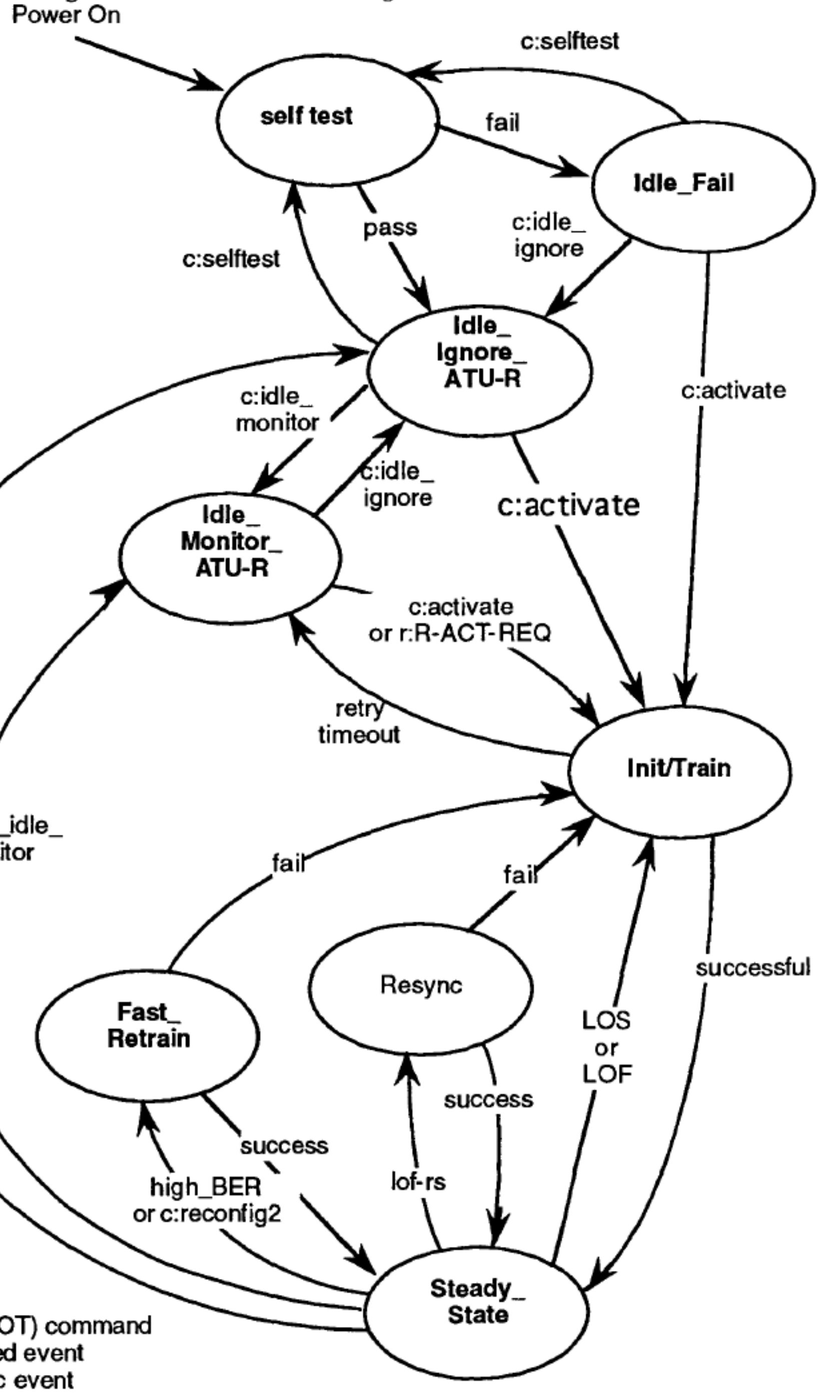
Annex A
(normative)

ATU-C and ATU-R state diagrams

A.1. Overview

Figure A.1 -- ATU-C state diagram



Key:
c:____ controller (e.g. ACOT) command
r:____ received or detected event
lof-rs: loss of frame/resync event
LOS: loss of signal alarm (timeout)
LOF: loss of frame alarm (lof timeout)

State definitions and glossary provided in separate tables

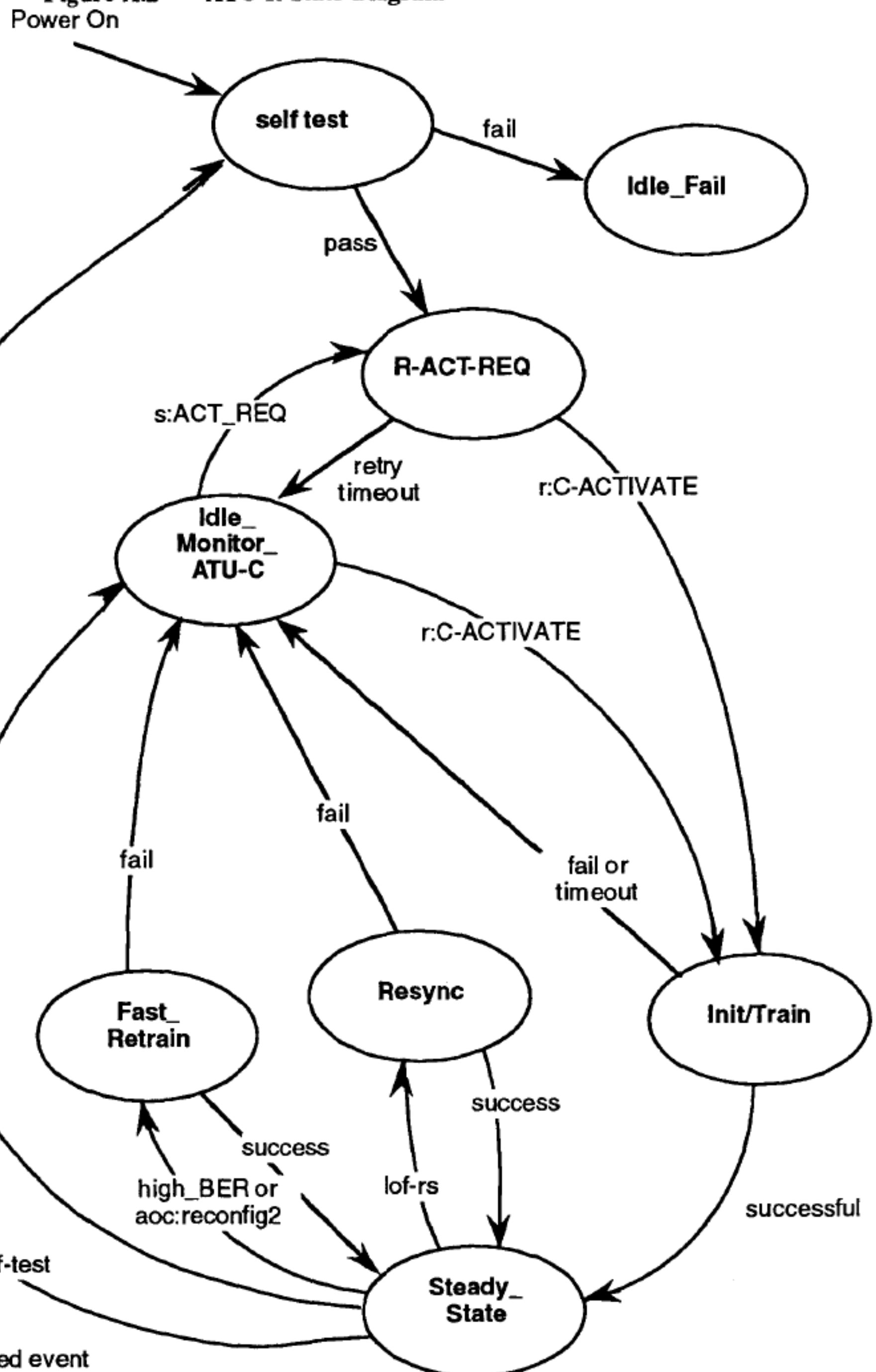
ATU-C State Definitions

State Name	Description
Selftest	Unit performs selftest. Transmitter and receiver off (quiet at U-C interface); no response to host control channel (e.g., ACOT)
Idle_Fail	(selftest failed) Initialize Train_Try_Counter Monitor host control channel if possible (ATU host controller can retrieve selftest results)
Idle_Ignore_ATU-R	Transmitter and receiver off; No response to R-ACT-REQ. Initialize Train_Try_Counter Monitor host control channel
Idle_Monitor_ATU-R	Transmitter off Initialize Train_Try_Counter Receiver on, monitoring for R-ACT_REQ; if detected, go to Init/Train state Monitor host control channel

Init/Train	A: Decrement Train_Try_Counter
	If Train_Try_Counter > 0
	Transmit C-ACTIVATE
	Start timer
	If receive R-ACK before timer expires, proceed with initialization/training
	else return to A:
	else
	Go to Idle_Monitor_ATU-R state

Steady State	Initialize Train_Try_Counter Perform steady state bit pump functions Allow bit swaps and non-intrusive reconfigurations (reconfig1) Monitor host control channel Monitor alarms, eoc, aoc
Resync	(State is entered when some algorithm, probably based on loss of ADSL synch framing, determines that resync is required) Attempt to find synch pattern and realign
Fast_Retrain	(State can only be entered if received signal is still present and if ADSL frame synch is still maintained) Channel ID and bit allocation calculation Reset Data Framing and V-interface circuits

Figure A.2 -- ATU-R State Diagram



Key:
- s:_____ set-top request
- r:_____ received or detected event
- lof-rs: loss of frame/resync event
- eoc: embedded operations channel command
- aoc: ADSL overhead control channel command
- LOS: loss of signal alarm (timeout)
- LOF: loss of frame alarm (lof timeout)

State definitions and glossary provided in separate tables

ATU-R State Definitions

State Name	Description
Selftest	Unit performs selftest. Transmitter and receiver off (quiet at U-R interface).
Idle_Fail	(selftest failed--no exit from this state, except to cycle power)
R-ACT-REQ	Initialize Act_Req_Counter A: Decrement Act_Req_Counter If Act_Req_Counter > 0 Transmit R-ACT-REQ for TBD msec Start timer If receive C-ACTIVATE before timer expires, go to Init/Train state else return to A: else Go to Idle_Monitor_ATU-C
Idle_Monitor_ATU-C	No xmit Monitor for C-ACTIVATE
Init/Train	Transmit R-ACK Proceed with Initialization and Training Sequence
Steady State	Perform steady state bit pump functions Allow bit swaps and non-intrusive reconfigurations (reconfig1) Monitor alarms, eoc, aoc
Resync	(State is entered when some algorithm, probably based on loss of ADSL synch framing, determines that resync is required) Attempt to find synch pattern and realign
Fast_Retrain	(State can only be entered if received signal is still present and if ADSL frame synch is still maintained) Channel ID and bit allocation calculation Reset Data Framing and T-interface circuits

Definitions

C-ACTIVATE	Activate tone transmitted by ATU-C for CO-initiated link starts (is actually the first step of initialization and training for the ATU-C); is also transmitted in response to an activation request (R-ACT-REQ) from the ATU-R if the ATU-C is allowed to respond.
R-ACT-REQ	Activation request tone transmitted by ATU-R to request link activation.
R-ACK	Acknowledgement tone transmitted by ATU-R in response to C-ACTIVATE.
lof-rs	Loss of ADSL frame synch/resync event. This event occurs when some algorithm, which may be vendor-specific, determines that a resync attempt is required. Note that this lof-rs event is probably (but not required to be) related to the sef (severely errored frame) and rdi (remote defect indicator) defects defined for Operations and Maintenance (see Section 11.3).
LOF	Loss of ADSL frame synchronization declared after sef timeout at ATU-C or rdi timeout at ATU-R, without successful resync.
LOS	Loss of received signal at "U" interface declared after timeout.
high_BER	High bit error rate in received data; detected by thresholding #crc errors over some period of time.
host control channel	An ATU-C configuration control channel from some host controller, such as an ACOT (ADSL Central Office Terminal), that controls one or more ATU-C line units. Note that this has no relationship or interworking with the 64 or 16 kbit/s "C" bearer channel, which is sometimes also called a control channel.
reconfig1	A channelization reconfiguration that can be accomplished without resetting certain key portions of the data framing, transmitter, or receiver functions, and thus can be performed without disrupting channels that would not change as a result of the reconfiguration. For example, if four 1.536 Mbit/s simplex channels are currently active and are all allocated to the interleave data buffer, then a reconfiguration that requires two of them to remain active, but two to be deallocated and replaced by a 3.088 Mbit/s channel would qualify as a reconfig1.
reconfig2	A channelization reconfiguration that requires resetting some key portion of the data framing, transmitter, or receiver functions and thus cannot be achieved without loss of some user data. This reconfiguration request will require a fast retrain. For example, a change from the default bearer channel rates to optional rates, such as a reconfiguration request from a single 6.144 Mbit/s simplex bearer to a 6.312 Mbit/s simplex bearer.
Train_Try_Counter	Number of initialization attempts ATU-C to make before returning to idle state. Initial value: 2 (TBR)
Act_Req_Counter	Number of initialization request attempts ATU-R to make before returning to idle state. Initial value: 2 (TBR)

*********EDITORIAL NOTE*********

Annex E
Status : Under Study (August 23/93 Mtg.)
Cont. 93-217
Source: NT

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Annex E
(informative)

Overvoltage, surge protection, and EMC

The purpose of this interface standard is to present the electrical characteristics of the ADSL access signals appearing at the network interface to the Customer Installation (CI), and to describe the physical interface between the network and the CI . Such phenomena as lightning and overvoltages due to inductive interference or power crosses lie beyond the scope of this standard. However, these topics are discussed in other readily-available documents, to which the interested reader is referred.

On lightning and 60-Hz overvoltages:

ANSI/IEEE C62.42-1986, *Guide for the application of gas tube arrester low-voltage surge-protective devices*

Lightning, radio frequency and 60-Hz disturbances at the Bell operating company network interface. Technical report TR-EOP-000001, issue 2, Piscataway, N.J.: Bellcore; 1987 June

Both documents contain useful information on the application of surge arresters and the loop electrical environment.

The following standards documents are also applicable:

ANSI/EIA/TIA-571-1991, *Environmental considerations for telephone terminals* . This standard discusses the normal operating environment of the telephone terminal equipment, fire hazards, and protection.

UL 1459, *Standard for telephone equipment.* This standard deals with safety considerations for telephone equipment.

The reader may also wish to consult:

Bodle, D.W. ; Gresh, P.A. *Lightning surges in paired telephone cable facilities.* Bell Syst. Tech. J. 40: 1961 March.

Gresh, P.A. *Physical and transmission characteristics of customer loop plant.* Bell Syst. Tech. J. 48: 1969 December.

Heirman, Donald N. *Time variations and harmonic content of inductive interference in urban/suburban and residential/rural telephone plants.* IEEE, 1976 Annals No. 512C0010.

Carrol, R. L.; Miller, P. S. *Loop transients at the customer station.* Bell Syst. Tech. J. 59(9): 1980 November..

Carrol, R. L. *Loop transients measurements in Cleveland,* South Carolina. Bell Syst. Tech. J. 59(9): 1980 November.

Measurement of transients at the subscriber termination of a telephone loop, CCITT, COM V-No. 53 (November 1983)

Batorsky, D. V.; Burke M.E., 1980 *Bell system noise survey of the loop plant.* AT&T Bell Lab. Tech. J. 63(5): 1984 May-June.

Koga, Hiraki; Motomitsu, Tamio *Lightining-induced surges in paired telephone subscriber cable in Japan.* IEEE Trans. Electromag. Comp. EMC-27: 1985 August.

Clarke, Gord; Coleman, Mike. *Study sheds light on overvoltage protection.* Telephony. 1986 November 24.

The power emitted by the ADSL is limited by the requirements in this standard. Notwithstanding any information contained or implied in this standard, it is assumed that the ADSL will comply with applicable FCC requirements on emission of electromagnetic energy. These requirements may be found in the Title 47, Code of Federal Regulations, Part 15 and Part 68, and other FCC documents.

*********EDITORIAL NOTE*********

Annex F
Status: Under Study (August 23/93 Mtg.)
Cont. ~~93-218~~
Source: NT

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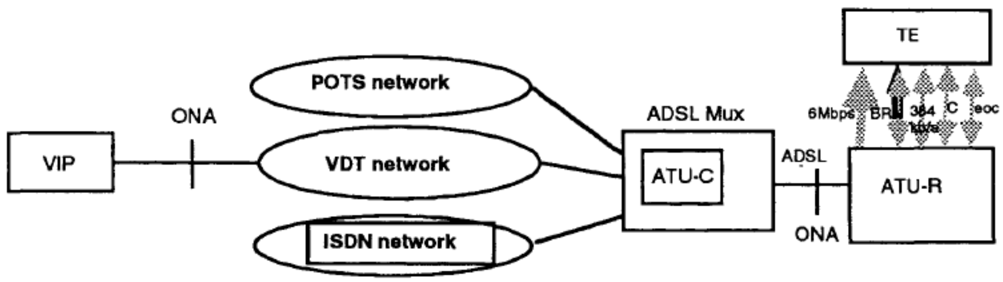
Annex - F
(informative)

Examples of ADSL services and applications

F.1 Services and Applications

Figure F-1 presents a basic network architecture for ADSL.

The market for ADSL services and applications can be segmented in various ways. Some potential application groups include: *entertainment, educational/institutional, telecommuting, small businesses* and *gaming*.



VDT - Video-dialtone
VIP - Video information Provider

Figure F-1 - Basic network architecture for ADSL

ADSL based services can offer users one major new innovation: real-time interactive multimedia services. In addition, the ability to support other application groups is important given that many homes are limited to a single copper pair.

The digital video revolution is opening opportunities for new classes of residential applications. Some of the potential applications can be grouped into the following categories, with examples of each group:

– Entertainment
- Movies on demand
  End-user dials into a service provider network to access a listed movie.
- Music on demand
  End-user dials into a service provider's network to access listed music.
- Interactive TV
  End-user accesses live and/or stored video/graphics is able to do searches with the help of pull-down menus, able to view more than one channels and select a channel of choice.

– Educational/Institutional
- Distant class rooms
  End-user is able to participate in a class remotely and interactively.
- On-line books and manuals
  End-user is able to access books and manuals on-line with the capability to turn pages, go to a certain page or section, do searches with keywords or subjects, highlight the lines online, make scratch-notes on the side of the book or on a scratchpad.
- Medical and health consultation
  End-user (hospital, say) is able to consult with and transmit medical images to a doctor at a remote site

– Telecommuting
- Work-at-home
  End-user (an employee, say) is able to access employer's workstations, printers, facsimile machines on LANs/WANs etc.
- Video-conferencing
  End-user is able to participate in a video-conference remotely with video in downstream and audio in upstream along with the workstation and screen sharing access.

– Small businesses
- Video-conferencing
  - Similar requirements as *Telecommuting*
- Credit-card picture/signature verifications
  - Small businesses can access a bank's or credit-card company's authorization database which transmits the card-holder's picture and signature to avoid fraud.

– Games
- Interactive games (user-to-server)
  End-user is able to play a game interactively from a remote server with various controls.
- Interactive games (user-to-user)
  One end-user is able to play a game interactively with another distant end-user with various controls.
- Off-track betting
  An individual can bet remotely for a live event from home.

F.2 Requirements

For the ADSL services listed in F.1, it is assumed that POTS will always be available with a control channel (C) and asymmetric channel (approximately 1.5, 3 or 6 Mbit/s). User will be able to subscribe to 2B + D and 384 kbit/s services. Some of the requirements for the above listed services and applications are listed below for information only:

– Entertainment
- Movies on demand
  - High-quality video (≥ 1.5 Mbit/s) + Audio (≥ 64 kbit/s) -> downstream
  - Remote control with pause, forward, reverse capability (approx. 100 bits/s) -> upstream
- Music on demand
  - High-quality audio (384 kbit/s - compressed or 1.5 Mbit/s with 16 bits PCM) -> downstream
  - Remote control with pause, forward, reverse capability (approx. 100 bits/s) -> upstream
- Interactive TV
  - High-quality video (≥ 1.5 Mbit/s) + normal Audio (≥ 64 kbit/s) -> downstream
  - Mouse or jockey control (≥ 16 kbit/s) -> upstream

– Educational/Institutional
- Distant class rooms
  - High-quality video (> 3 Mbit/s) + audio (384 kbit/s) -> downstream
  - Audio (384 kbit/s) -> upstream
- On-line books and manuals
  - High-quality video (> 3 Mbit/s) + data -> downstream
  - Mouse control (pull-down menus) with the capability to turn pages, go to certain page or section, to searches with keywords or subjects, highlight the lines online, make scratch-notes on the side of the book or on a scratchpad (max. of 64 kbit/s) -> upstream
- Medical and health consultation
  - High-quality video (> 1.5 Mbit/s) + voice + data -> downstream
  - Mouse like controls to zoom-in and out on the grpahical image being transmitted (≥ 64 kbit/s) -> upstream

– Telecommuting
- Work-at-home
  - High-quality video (> 1.5 Mbit/s) + voice + data -> downstream
  - Audio (384 kbit/s) + data -> upstream

• Video-conferencing
  - Medium-quality video (≥ 1.5 Mbit/s) + graphics + data + voice -> downstream
  - Graphics + data + voice (384 kbit/s for all together) -> upstream

– Small businesses
• Screen-sharing
  - High-quality graphics (384 kbit/s) + data + voice -> downstream
  - Voice + graphics (384 kbit/s) + data -> upstream
• Video-conferencing
  - Medium-quality video (= 1.5 Mbit/s) + graphics + data + voice -> downstream
  - Video (= 1.5 Mbit/s) + graphics + data + voice -> upstream
• Credit-card picture/signature verifications
  - High-quality graphics + data + voice (384 kbit/s for all together) -> downstream
  - Voice + graphics + data (384 kbit/s for all together) -> upstream

– Games
• Interactive games (user-to-server)
  - High-speed video (≥ 3 to 6 Mbit/s) + Audio -> downstream
  - Speech-recognition, audio, jockey or mouse controls -> upstream
• Interactive games (user-to-user)
  - High-speed video (≥ 3 to 6 Mbit/s) + Audio -> downstream
  - Speech-recognition, audio, jockey or mouse controls (≤ 64 kbit/s)-> upstream
• Off-track betting
  - High-quality video (≥ 3 to 6 Mbit/s) + Audio + data -> downstream
  - Audio + data + control (≤16 kbit/s) -> upstream

Figure F.2 presents a mapping of downstream and upstream channel capacities with the services that can be supported.

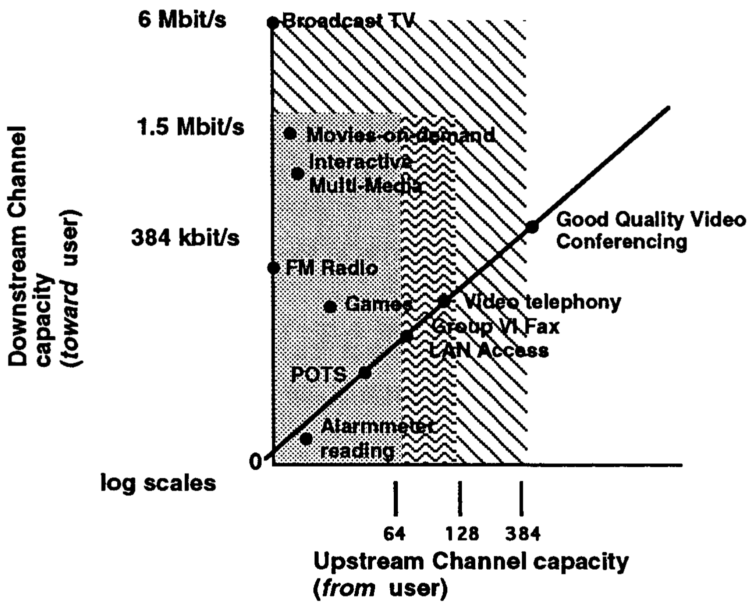


Figure F-2 - Applications based on upstream and downstream channel capacity

final

T1E1.4/95-007R2

T1/LB-440

T1.413-1995

Draft American National Standard
for Telecommunications–

Network and Customer Installation Interfaces

Asymmetric Digital Subscriber Line (ADSL) Metallic Interface

Secretariat

Alliance for Telecommunications Industry Solutions

Abstract

This standard presents the electrical characteristics of the Asymmetric Digital Subscriber Line (ADSL) signals appearing at the network interface. The physical interface between the network and the customer installation is also described. The transport medium for the signals is a single twisted-wire pair that supports both Message Telecommunications Service (POTS) and full-duplex (simultaneous two-way) and simplex (from the network to the customer installation) digital services.

This interface standard provides the minimal set of requirements for satisfactory transmission between the network and the customer installation. Equipment may be implemented with additional functions and procedures.

Approved Month__, 19__

American National Standards Institute, Inc.

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Foreword (This foreword is not part of American National Standard T1E1.4____)

This specification of the layer 1 characteristics of the Asymmetrical Digital Subscriber Line (ADSL) interface to metallic loops was initiated under the auspices of the Accredited Standards Committee on Telecommunications, T1. The specification should be of interest and benefit to network providers and customers using multimedia services.

A single twisted pair of telephone wires is used to connect two ADSL units: one at the central office end (an ATU-C) and one at the remote end (an ATU-R). This standard has been written to define the transport capability of these units on a wide variety of wire pairs and with typical impairments, and to help ensure proper interfacing and interworking when the two units are manufactured and provided independently.

The ADSL simultaneously conveys all of the following: a downstream simplex bearer, a duplex bearer, a baseband analog duplex channel, and ADSL line overhead for framing, error control, operations, and maintenance. Nominal downstream bearer rates from 1.536 to 7 Mbit/s may be programmed. Duplex bearer aggregate rates from 16 to 640 kbit/s may be programmed.

Two categories of performance are specified. Category I performance is required for compliance with this standard; performance enhancement options are not required for category I equipment. Category II is a higher level of performance (i.e., longer lines and greater impairments). Category II characteristics are not required for compliance with this standard. Three optional enhancements – trellis coding, transmit power boost, and echo cancellation – are defined for Category II equipment.

A future issue of this standard may address the items listed in Annex J.

Suggestions for improvements of this standard are welcome. They should be sent to the Alliance for Telecommunications Industries Solutions, 1200 G Street NW, Suite 500, Washington, DC 20005.

There are nine annexes to this standard; four are normative, and are considered part of the standard.

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Technical Subcommittee T1E1 on Carrier-to-Customer Premises Equipment Interfaces, which is responsible for the development of this standard, had the following members:

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Representative

1 Scope and purpose

1.1 Scope

This standard describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. The requirements of this standard apply to a single asymmetric digital subscriber line (ADSL). ADSL allows the provision of Plain Old Telephone Service (POTS) and a variety of digital channels. In the direction from the network to the customer premises the digital channels may consist of full duplex low-speed channels and simplex high-speed channels; in the other direction only low-speed channels are provided.

The transmission system is designed to operate on two-wire twisted metallic cable pairs with mixed gauges. The standard is based on the use of cables without loading coils, but bridged taps are acceptable with the exception of unusual situations.

Functions included in the Service Modules other than those associated with the ATU-R to Service Module interface are beyond the scope of this standard

Specifically, this standard:

– describes the transmission technique used to support the simultaneous transport of POTS and both simplex and full-duplex digital channels on a single twisted-pair ;

– defines the combined options and ranges of the digital simplex and full-duplex channels provided;

– defines the line code and the spectral composition of the signals transmitted by both ATU-C and ATU-R;

– specifies the receive signals at both the ATU-C and ATU-R;

– describes the electrical and mechanical specifications of the network interface;

– describes the organization of transmitted and received data into frames;

– defines the functions of the operations channel;

– defines the ATU-R to service module(s) interface functions.

NOTE – The user's attention is drawn to the possibility that compliance with this standard may require use of an invention covered by patent rights.

By publication of this standard no position is taken with respect to the validity of any rights in connection with such a patent. The patent holder has, however, filed a statement of willingness to grant a license under these rights on reasonable and non-discriminatory terms and conditions to applicants desiring to obtain such a license. Details may be obtained from the secretariat.

1.2 Purpose

This interface standard defines the minimal set of requirements to provide satisfactory simultaneous transmission between the network and the customer interface of POTS and a variety of high-speed simplex and low-speed full duplex channels. The standard permits network providers an expanded use of existing copper facilities. All Layer 1 aspects required to ensure compatibility between equipment in the network and equipment at a remote location are specified. Equipment may be implemented with additional functions and procedures.

2 Normative Referenced standards

The following standards contain provisions that, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

ANSI T1.401-1993; *Telecommunications–Interface between carriers and customer installations–Analog voice-grade switched access lines using loop-start and ground-start signaling.*

ANSI/EIA/TIA-571, *Environmental considerations for telephone terminals, 1991*

ANSI T1.231-1993; *Telecommunications–In-service Layer 1 digital transmission performance monitoring*

ANSI/EIA RS-422A; *Electrical charaacteristics of balanced voltage digital interface circuits,* 1978

IEEE Standard 455-1985, *Test procedures for measuring longitudinal balance of telephone equipment operating in the voice band*

3 Definitions, abbreviations, acronyms and symbols

3.1 Definitions

3.1.1 aggregate data rate: data rate transmitted by an ADSL system in any one direction; it includes both net data rate and data rate overhead used by the system for crc, eoc, synchronization of the various data streams, and fixed indicator bits for OAM; it does not include FEC redundancy.

3.1.2 bearer channel: a user data stream of a specified data rate that is transported transparently by an ADSL system, and carries a bearer service; sometimes abbreviated to bearer.

3.1.3 bearer service: the transport of data at a certain rate without regard to its content, structure, or protocol.

3.1.4 bridged taps: sections of unterminated twisted-pair cable connected in parallel across the cable under consideration.

3.1.5 Category I: a default set of requirements that shall be met by all compliant equipment.

3.1.6 Category II: an enhanced set of requirements that may be met by the provision of certain options.

3.1.7 channelization: allocation of the net data rate to bearer channels.

3.1.8 downstream : ATU-C to ATU-R direction.

3.1.9 loading coils: inductors placed in series with the cable at regular intervals in order to improve the voice-band response.

3.1.10 net data rate: total data rate that is available to user data in any one direction; for the downstream direction this is the sum of the net simplex and duplex data rates.

3.1.11 splitter: a low-pass/high-pass pair of filters that separate high (ADSL) and low (POTS) frequency signals.

3.1.12 transport class: the set of bearer channel data rates and multiplex configurations that may be simultaneously transported on a given loop, based on the maximum aggregate data rate supported by that loop.

3.1.13 upstream: ATU-R to ATU-C direction

3.2 Abbreviations, acronyms and symbols

ADC	analog to digital converter
ADSL	asymmetric digital subscriber line
AEX	byte inserted in the transmitted ADSL frame structure to provide synchronization capacity that is shared among ASX channels
AGC	automatic gain control
aoc	ADSL overhead control channel
AS0–3	downstream simplex sub-channel designators
ASX	any one of the simplex channels AS0 to AS3
ATM	asynchronous transfer mode
ATU-C	ADSL transceiver unit, central office end
ATU-R	ADSL transceiver unit, remote terminal end
B_F	the number of bytes in a data stream allocated to the fast (i.e., non-interleaved) buffer

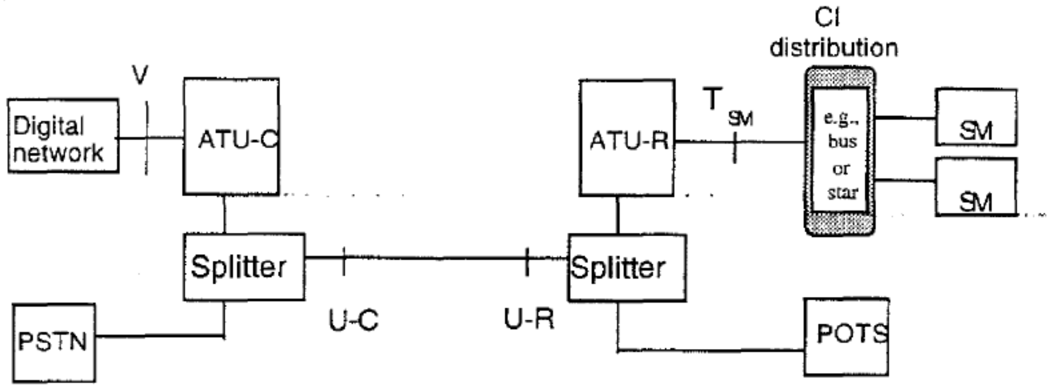
B_I	the number of bytes in a data stream allocated to the interleaved buffer
BRA	basic rate access
CI	customer installation
CO	central office
CSA	carrier serving area
CSA loops	a set of loops within the CSA that are defined by T1 technical report TR-028-1994
crc-8f	cyclic redundancy check using CRC-8 code - fast data
crc-8i	cyclic redundancy check using CRC-8 code - interleaved data
DAC	digital to analog converter
dBm	dB milliwatt; 0 dBm = 1 milliwatt
DMT:	discrete multitone
DSL	digital subscriber line
EC	echo canceling
eoc	embedded operations channel
ERL	echo return loss, as defined by IEEE Std 743-1984
es	errored second
FDM	frequency-division multiplexing
febe-f	far-end block error count - fast data
febe-i	far-end block error count - interleaved data
fecc-f	forward error correction count - fast data
fecc-i	forward error correction count - interleaved data
FEC:	forward error correction
FEXT	far-end cross talk
HDSL	high-rate digital subscriber line
ib0 - 23	indicator Bit(s)
ID code	vendor identification code
IDFT	inverse discrete fourier transform
ISDN	Integrated Services Digital Network
ISDN–BRA	ISDN basic rate access
kbit/s	kilo bits per second
LEX	byte inserted in the transmitted ADSL frame structure to provide synchronization capacity that is shared among LSX and ASX channels
lof	loss of frame
lopr	loss of power
los	loss of signal
LS0 - 2	duplex sub-channel designators
ms	millisecond
NI	network interface
$N_{m,f}$	number of bytes in a fast mux data frame
$N_{m,i}$	number of bytes in an interleaved mux data frame
NEXT	near-end cross talk
OAM	operations, administration and maintenance
OSI	open systems interconnection (7 layer model)
POTS	plain old telephone service (also known as message telecommunications service, MTS)
PRD	pseudo-random downstream
PRU	pseudo-random upstream
PSD	power spectral density
PSTN	public switched telephone network
PRBS	pseudo-random bit sequence
P_{dsf}	number of FEC parity bytes for fast buffer
P_{dsi}	number of FEC parity bytes for interleaved buffer
QAM	quadrature amplitude modulation
rdi	remote defect indication
RT	remote terminal
sc0 - 7	synchronization control bit(s)
sef	severely errored frame

sefs	severely errored frame second
SINAD	signal-to-noise plus distortion (ratio)
SM	service module
SONET	synchronous optical network
SRL	singing return loss, as defined by IEEE Std 743-1984
SRL low	SRL in a band from approximately 260 to 500 Hz
SRL high	SRL in a band from approximately 2200 to 3400 Hz
STM	synchronous transfer mode
T-SM	interface(s) between ATU-R and SM(s)
U-C:	loop interface - central office end
U-R	loop interface - remote terminal end
VDT	video dial tone
V	logical interface between ATU-C and a digital network element such as one or
more	switching systems
VIP	video information provider
4QAM	4-point QAM (i.e., two bits per symbol)
⊕:	exclusive-or; modulo-2 addition

4 Reference models

4.1 System reference model

The system reference model shown in figure 1 illustrates the functional blocks required to provide ADSL service.



NOTES

1 The V interface is defined in terms of logical functions; not physical.
2 The V interface may consist of interface(s) to one or more switching systems.
3 Implementation of the V and T_{SM} interfaces is optional when interfacing elements are integrated into a common element.
4 The splitter function may be integrated into the ATU
5 A digital carrier facility (e.g., SONET extension) may be interposed at the V interface when the ATU-C is located at a remote site.
6 The nature of the CI distribution (e.g., bus or star, type of media) is for further study.
7 More than one type of T_{SM} interface may be defined, and more than one type of T-sm interface may be provided from an ATU-R.
8 Due to the asymmetry of the signals on the line, the transmitted signals shall be distinctly specified at the U-R and U-C reference points.
9 A future issue of this standard may deal with CI distribution requirements.

Figure 1 — ADSL functional reference model

4.2 ATU-C transmitter reference model

Figure 2 is a block diagram of an ADSL Transceiver Unit-Central office (ATU-C) transmitter showing the functional blocks and interfaces that are referenced in the following clauses.

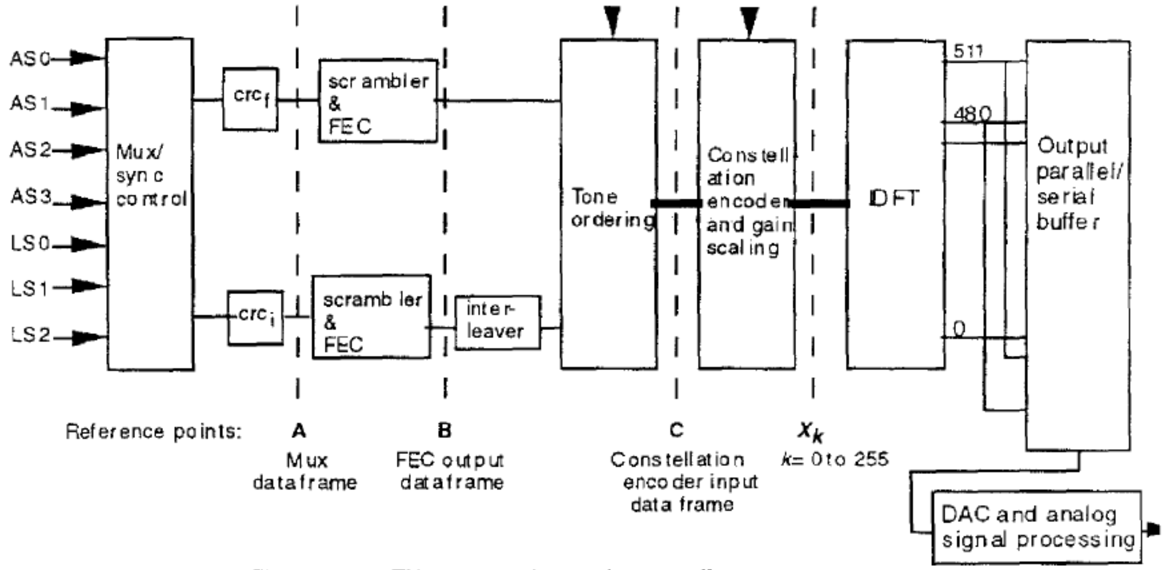


Figure 2 – ATU-C transmitter reference diagram

4.3 ATU-R transmitter reference model

Figure 3 is a block diagram of an ATU-R transmitter showing the functional blocks and interfaces that are referenced in the following clauses.

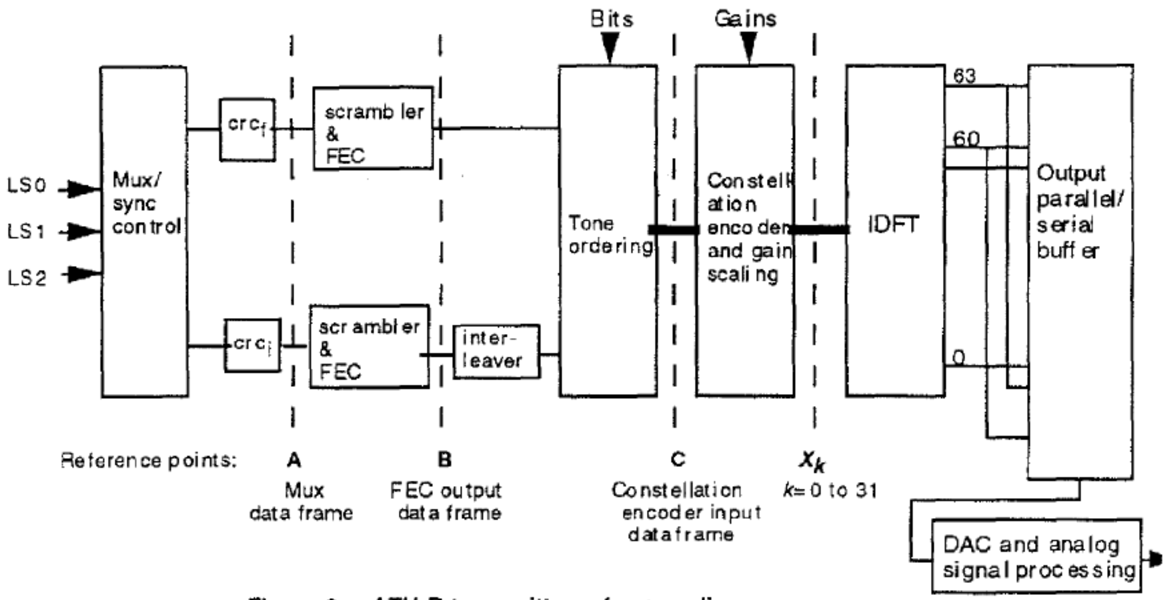


Figure 3 – ATU-R transmitter reference diagram

5 Transport capacity

An ADSL system may transport up to seven bearer channels (bearers) simultaneously:
- up to four independent downstream simplex bearers (unidirectional downstream);
- up to three duplex bearers (bi-directional , downstream and upstream).

The three duplex bearers may alternatively be configured as independent unidirectional simplex bearers, and the rates of the bearers in the two directions (downstream and upstream) do not need to match.

All bearer channel data rates can be programmed in any combination of multiples of 32 kbit/s. Other data rates (non-integer multiples of 32 kbit/s) can also be supported, but will be limited by the ADSL system's available capacity for synchronization (see notes 1 and 2).

Four transport classes are defined for the downstream simplex bearers based on multiples of 1.536 Mbit/s up to 6.144 Mbit/s. Data rates are also defined for duplex bearers to carry a control channel and ISDN channels (basic rate and 384 kbit/s). The ADSL data multiplexing format is flexible enough to allow other transport data rates, such as channelizations based on existing 1.544 or 2.048 Mbit/s formats, and to allow definition of other channelizations in the future in order to accommodate evolving Synchronous or Asynchronous Transfer Modes (STM or ATM) network formats (singly or in combination).

The maximum net data rate transport capacity of an ADSL system will depend on the characteristics of the loop on which the system is deployed and on certain configurable options that affect overhead (see note 3).

Each bearer channel shall be individually assigned to an ADSL sub-channel for transport, and the ADSL sub-channel rate shall be configured during the initialization and training procedure to match the bearer rate.

The transport capacity of an ADSL system per se is defined only as that of the high-speed data streams. When, however, an ADSL system is installed on a line that also carries POTS signals the overall capacity is that of POTS plus ADSL (see clauses 8 and 10 for details on POTS related requirements).

NOTES
1 Part of the ADSL system overhead is shared among the bearer channels for synchronization. The remainder of each channel's data rate that exceeds a multiple of 32 kbit/s shall be transported in this shared overhead.
2 The rates for the downstream simplex bearer channels are based on unframed 1.536 Mbit/s structures in order to be consistent with the expected evolution of network switching. ADSL deployments may need to interwork with DS1 (1.544 Mbit/s) data. The ADSL system overhead and data synchronization (see 6.2.2) provides enough capacity to support the framed DS1 data streams transparently (i.e., the entire DS1 signal is passed through the ADSL transmission path without interpretation or removal of the framing bits and other overhead).
3 One part of the ADSL initialization and training sequence estimates the loop characteristics to determine whether the number of bytes per Discrete MultiTone (DMT) frame required for the requested configuration's aggregate data rate can be transmitted across the given loop. The net data rate is then the aggregate data rate minus ADSL system overhead. Part of the ADSL system overhead is dependent on the configurable options, such as allocation of user data streams to interleaving or non-interleaving data buffers within the ADSL frame (discussed in 6.2, 6.4.2, 7.2, and 7.4.2), and part of it is fixed.

5.1 Simplex bearers

Simplex bearers in the downstream direction are specified herein; the use of upstream simplex bearers is for further study.

5.1.1 Data rates for downstream simplex bearers based on multiples of 1.536 Mbit/s

The default data rates for the four possible simplex bearer channels that may be transported downstream over an ADSL system are

- 1.536 Mbit/s;
- 3.072 Mbit/s;
- 4.608 Mbit/s;
- 6.144 Mbit/s.

The ADSL system may use up to four sub-channels, named AS0, AS1, AS2, and AS3, to transport the downstream simplex bearer channels. An ADSL sub-channel's rate shall match the rate of the bearer channel that it transports, subject to the restrictions given in table 1.

Table 1 – ADSL sub-channel rate restrictions for default bearer rates

Sub-channel designations	Sub-channel data rate	Allowed values of n_x
AS0	$n_0 \times 1.536$ Mbit/s	$n_0 = 0, 1, 2, 3$ or 4
AS1	$n_1 \times 1.536$ Mbit/s	$n_1 = 0, 1, 2,$ or 3
AS2	$n_2 \times 1.536$ Mbit/s	$n_2 = 0, 1,$ or 2
AS3	$n_3 \times 1.536$ Mbit/s	$n_3 = 0$ or 1
NOTE - Rates equivalent to multiple DS1s are also supported.		

The maximum number of sub-channels that may be active at any given time and the maximum number of bearer channels that can be transported simultaneously by an ADSL system will depend on the transport class (as described in 5.1.1.1 through 5.1.1.4) that can be supported by the specific loop and on the configuration of the active sub-channels. Switching on demand among the configurations allowed by a given transport class is for further study.

To comply with this standard the AS0 sub-channel and at least transport classes 1 (5.1.1.1) and 4 (5.1.1.4) shall be supported. Support of sub-channels AS1, AS2, AS3, and transport classes 2, 3, and 2M is optional.

5.1.1.1 Downstream simplex bearer configurations for transport class 1 (shortest range, highest capacity)

The net simplex bearer capacity on transport class 1 is 6.144 Mbit/s, which may be composed of any combination of one to four bearer channels with $n \times 1.536$ Mbit/s rates. Systems shall support at least a 6.144 Mbit/s bearer channel on sub-channel AS0. The following transport class 1 configurations are optional:

- one 4.608 Mbit/s bearer channel and one 1.536 Mbit/s bearer channel;
- two 3.072 Mbit/s bearer channels;
- one 3.072 Mbit/s bearer channel and two 1.536 Mbit/s bearer channels;
- four 1.536 Mbit/s bearer channels.

5.1.1.2 Downstream simplex bearer configurations for optional transport class 2

The net simplex bearer capacity on transport class 2 is 4.608 Mbit/s, which may be composed of any combination of one to three bearer channels with $n \times 1.536$ Mbit/s rates. Systems, at their option, may provide any and all bearer rates. Transport class 2 configuration options are:

- one 4.608 Mbit/s bearer channel;
- one 3.072 Mbit/s bearer channel and one 1.536 Mbit/s bearer channel;
- three 1.536 Mbit/s bearer channels.

ADSL sub-channel AS3 shall not be used in this configuration.

5.1.1.3 Downstream simplex bearer configurations for optional transport class 3

The net simplex bearer capacity on transport class 3 is 3.072 Mbit/s, which may be composed of one or two bearer channels with $n \times 1.536$ Mbit/s rates. Systems, at their option, may provide either or both bearer rates. Transport class 3 configuration options are:

- one 3.072 Mbit/s bearer channel;
- two 1.536 Mbit/s bearer channels.

ADSL sub-channels AS2 and AS3 shall not be used in this configuration.

5.1.1.4 Downstream simplex bearer configurations for transport class 4 (longest range, lowest capacity)

Only one downstream simplex bearer option can be supported in transport class 4. The bearer channel capacity of one 1.536 Mbit/s bearer channel shall be transported on sub-channel AS0.

5.1.2 Optional data rates for downstream simplex bearers based on multiples of 2.048 Mbit/s

ADSL equipment may include channelization options other than those defined in 5.1.1. For example, the rate structure outlined in this subclause accommodates a digital hierarchy based on multiples of 2.048 Mbit/s.

This 2.048 Mbit/s rate structure is optional, both in implementation of equipment and in the provision of service. Equipment or service implementation at the 1.536 Mbit/s rate (or multiples) but not the 2.048 Mbit/s rate would still fully conform to the standard. Information related to 2.048 Mbit/s applications may be found in annex H.

Bearer channels based on 2.048 Mbit/s that may optionally be transported downstream over an ADSL system are

- 2.048 Mbit/s;
- 4.096 Mbit/s;
- 6.144 Mbit/s.

The entire framed 2.048 Mbit/s structure is treated as a bearer data stream; the use of a lower payload rate is for further study.

An ADSL system supporting these options may use up to three of the downstream simplex sub-channels, AS0, AS1, and AS2, to transport the bearer channels. An ADSL sub-channel's rate shall match the rate of the bearer channel that it transports, subject to the restrictions given in table 2.

Table 2 - ADSL Sub-channel rate restrictions 2.048 Mbit/s (optional)

Sub-channel designations	Sub-channel data rate	Allowable values of n_x
AS0	$n_0 \times 2.048$ Mbit/s (optional)	$n_0 = 0, 1, 2,$ or 3
AS1	$n_1 \times 2.048$ Mbit/s (optional)	$n_1 = 0, 1,$ or 2
AS2	$n_2 \times 2.048$ Mbit/s (optional)	$n_2 = 0,$ or 1

The maximum number of sub-channels that may be active at any given time, and the maximum number of bearer channels that can be transported simultaneously by an ADSL system depends on the transport class (as described in 5.1.2.1 through 5.1.2.3) that can be supported by the specific loop on which the system is deployed, and the configuration of the active sub-channels.

5.1.2.1 Downstream simplex bearer configurations for optional transport class 2M-1

The simplex bearer capacity on the optional transport class 2M-1 is 6.144 Mbit/s, which may be composed of any combination of one to three bearer channels with $n \times 2.048$ Mbit/s rates. Systems, at their option, may provide any and all bearer rates. Transport class 2M-1 configuration options are:

- one 6.144 Mbit/s bearer channel;
- one 4.096 Mbit/s bearer channel and one 2.048 Mbit/s bearer channel;
- three 2.048 Mbit/s bearer channels.

5.1.2.2 Downstream simplex bearer configurations for optional transport class 2M-2

The combined simplex bearer capacity on optional transport class 2M-2 is 4.096 Mbit/s, which may be composed of one or two bearer channels with $n \times 2.048$ Mbit/s rates. Systems, at their option, may provide either or both bearer rates. Transport class 2M-2 configuration options are:

- one 4.096 Mbit/s bearer channel;
- two 2.048 Mbit/s bearer channels.

ADSL sub-channel AS2 shall not be used in this configuration.

5.1.2.3 Downstream simplex bearer configurations for optional transport class 2M-3

Only one downstream simplex bearer option--2.048 Mbit/s transported on ADSL sub-channel AS0--can be supported in transport class 2M-3.

5.1.3 Options for transporting downstream simplex ATM data streams

ADSL equipment may also provide the capability to transport ATM data as a single downstream simplex data stream.

If this capability is provided the ADSL bearer channel rates shall be based on

– $n \times 1.536$ Mbit/s user data content, where $n = 1 – 4$;
– AAL1 cell format (ATM Adaption Layer 1), in which each 53-byte ATM cell transports 47 bytes of user data, yielding ATM data cell bit rates of $n \times 1.536$ Mbit/s $\times 53/47$;
– rounding the ATM data cell bit rate up to the nearest integer multiple of 32 kbit/s by insertion of idle cells (and possibly OAM cells as suggested by CCITT Rec. I.610) by an ATM cell processor on the network side of the V-interface.

Only the ADSL downstream simplex sub-channel AS0 shall be used, resulting in a single configuration option for the downstream simplex bearer, and its rate depends on the transport class as specified in table 3.

Table 3 – Downstream ATM data cell bit rates

Transport Class	Bearer channel rate	ATM data cell bit rate
1	6.944 Mbit/s	6.928340 Mbit/s
2	5.216 Mbit/s	5.196255 Mbit/s
3	3.488 Mbit/s	3.464170 Mbit/s
4	1.760 Mbit/s	1.732085 Mbit/s

5.1.4 Upstream simplex bearers.

Upstream simplex bearers are for further study.

5.2 Duplex bearers

Up to three duplex bearer channels may be transported simultaneously by an ADSL system. One of these is the mandatory control (C) channel. Data rates for this channel, which shall always be active, are specified in 5.2.1.

Depending on the maximum aggregate rate that can be supported on the specific loop and on the options implemented, specific limitations apply to the other two optional duplex ADSL sub-channels. Only certain allowed combinations of these may be active in any given configuration; these are defined in 5.2.2.

5.2.1 Data rates for the control channel (mandatory duplex channel)

The C channel shall transport CI to CI (e.g., control of services) and CI-to-network signaling (i.e., call setup and selection of services) for the downstream simplex bearer services, and it may also transport some or all of the CI-to-network signaling for the optional duplex services. For transport classes 4 and 2M-3 the C channel shall operate at 16 kbit/s, and be transported within the ADSL synchronization overhead (see 6.2); for all other classes it shall operate at 64 kbit/s, and be transported on ADSL sub-channel LS0.

5.2.2 Data rates for the optional duplex bearer channels

Two optional duplex bearer channels may be transparently transported by an ADSL system, depending on the service offered by the network provider.

If these bearer channels are transported the sub-channel assignments and data rates shall be:

- ADSL sub-channel LS1 at 160 kbit/s;
- ADSL sub-channel LS2 at 384 kbit/s or 576 kbit/s.

The duplex options for the four transport classes are given in table 4.

Table 4 – Maximum optional duplex bearer channels supported by transport class

Transport class	Optional duplex bearers that may be transported (note 1)	Active ADSL sub-channels
1 or 2M-1 (minimum range)	Configuration 1: 160 kbit/s + 384 kbit/s; Configuration 2: 576 kbit/s only	LS1, LS2 LS2 only
2, 3 or 2M-2 (mid range)	Configuration 1: 160 kbit/s only Configuration 2: 384 kbit/s only (see note 2)	LS1 only LS2 only
4 or 2M-3 (maximum range)	160 kbit/s only	LS1 only

NOTES

1 When the 160 kbit/s optional duplex bearer is used to transport ISDN BRA, all signaling associated with the ISDN BRA (160 kbit/s) is carried by the D channel of the 2B + D signal embedded in the 160 kbit/s. Signaling for the 576 kbit/s, 384 kbit/s and non-ISDN 160 kbit/s duplex bearers may be included in the C channel, which is shared with the signaling for the downstream simplex bearer channels.

2 Whether transport classes 2, 3, or 2M-2 should support the 576 kbit/s optional duplex bearer is for further study.

5.2.3 Options for transporting duplex ATM data streams on the optional duplex channel LS2

ADSL equipment providers may also at their discretion provide the capability to transport an ATM cell stream on the optional duplex LS2 channel.

If this duplex ATM transport capability is provided the bearer channel rates shall be based on:

– 384 kbit/s or 576 kbit/s user data content;
– AAL1 or AAL5 cell format (ATM Adaption Layer 1: each 53-byte ATM cell transports 47 bytes of user data) yielding ATM data cell bit rates of 384 × (53/47) kbit/s or 576 × (53/47) kbit/s;
– rounding the ATM data cell bit rate to the nearest integer multiple of 32 kbit/s by insertion of idle cells (and possibly OAM cells as suggested by CCITT Recommendation I.610) by an ATM cell processor on the network side of the V-interface and on the service module side of the T-interface.

Table 5 – Optional duplex ATM data cell bit rates for LS2

ADSL optional LS2 channel rate	ATM data cell bit rate
448 kbit/s	443.0213 kbit/s
672 kbit/s	649.5320 kbit/s

NOTE The configuration options for each transport class are based on the default (non-ATM) data rates. Use of the optional ATM rates may reduce the loop reach or limit the configuration options possible on a given loop.

5.3 Combined options

5.3.1 Options for bearer channel rates based on downstream multiples of 1.536 Mbit/s

As specified in 5.1 and 5.2, different ADSL sub-channel and bearer configuration options may be provided for each of the transport classes. Within a given transport class, the allowable downstream simplex bearer and duplex bearer configurations may be treated independently. The net data rates (i.e., maximum bearer capacities) based on multiples of 1.536 Mbit/s for transport

classes 1 and 4 (and for optional classes 2 and 3 if they are provided) shall be as summarized in table 6.

Table 6 – Bearer channel options by transport class for bearer rates based on downstream multiples of 1.536 Mbit/s

Transport class:	1	2	3	4
Downstream simplex bearers:				
Maximum capacity	6.144 Mbit/s	4.608 Mbit/s	3.072 Mbit/s	1.536 Mbit/s
Bearer channel options	1.536 Mbit/s, 3.072 Mbit/s, 4.608 Mbit/s, 6.144 Mbit/s	1.536 Mbit/s, 3.072 Mbit/s, 4.608 Mbit/s	1.536 Mbit/s, 3.072 Mbit/s	1.536 Mbit/s
Maximum active sub-channels	4 (AS0,AS1, AS2,AS3)	3 (AS0, AS1, AS2)	2 (AS0, AS1)	1 (AS0 only)
Duplex bearers:				
Maximum capacity	640 kbit/s	608 kbit/s	608 kbit/s	176 kbit/s
Bearer channel options	576 kbit/s, 384 kbit/s, 160 kbit/s, C (64 kbit/s)	see note 384 kbit/s, 160 kbit/s, C (64 kbit/s)	see note 384 kbit/s, 160 kbit/s, C (64 kbit/s)	160 kbit/s, C (16 kbit/s)
Max. active sub-channels	3 (LS0, LS1, LS2)	2 (LS0,LS1) or (LS0, LS2)	2 (LS0,LS1) or (LS0, LS2)	2 (LS0,LS1)

NOTE – Whether transport classes 2 or 3 should support the 576 kbit/s optional duplex bearer is for further study.

The configuration shall be specified by the B_F and B_I parameters (described in 6.2, 7.2, and 12.8) for each bearer channel.

5.3.2 Options for bearer channel rates based on downstream multiples of 2.048 Mbit/s

The maximum bearer capacities for the three possible transport classes for the optional bearer rates based on 2.048 Mbit/s are summarized in table 7.

Table 7 – Bearer channel options by transport class – optional bearer rates based on downstream multiples of 2.048 Mbit/s

Transport class:	2M-1	2M-2	2M-3
Downstream simplex bearers			
Maximum capacity	6.144 Mbit/s	4.096 Mbit/s	2.048 Mbit/s
Bearer channel options	2.048 Mbit/s, 4.096 Mbit/s, 6.144 Mbit/s	2.048 Mbit/s, 4.096 Mbit/s	2.048 Mbit/s
Max. active sub-channels	3 (AS0,AS1,AS2)	2 (AS0,AS1)	1 (AS0 only)
Duplex bearers			
Maximum capacity	640 kbit/s	608 kbit/s	176 kbit/s
Bearer channel options	576 kbit/s, 384 kbit/s, 160 kbit/s, C (64 kbit/s)	see note 384 kbit/s, 160 kbit/s, C (64 kbit/s)	160 kbit/s, C (16 kbit/s)
Max. active sub-channels	3 (LS0, LS1, LS2)	2 (LS0,LS1 or (LS0, LS2)	2 (LS0, LS1)

NOTE: Whether transport class 2M-2 should support the 576 kbit/s optional duplex bearer is for further study.

The configuration shall be specified by the B_F and B_I parameters (described in 6.2, 7.2, and 12.8) for each bearer channel.

5.3.3 Options for bearer channel options transporting ATM cell streams

For optional bearer rates transporting an ATM cell stream in the downstream simplex channel, up to four transport classes, roughly equivalent to the default bearer transport classes, can be defined. Only one configuration option is expected to be supported by each transport class: that of the single downstream simplex channel carrying the ATM data and the single mandatory duplex channel to carry signaling and service control traffic. Equipment and service providers may optionally provide duplex bearers over loops that can support a higher aggregate ADSL rate than those representative of the transport classes. The optional ATM bearer rates are summarized in table 8.

Table 8 – Bearer channel options by transport class for optional ATM bearer rates

Transport class:	1	2	3	4
Downstream simplex bearers				
Aggregate ATM data cell bit rate	6.928340 Mbit/s	5.196255 Mbit/s	3.464170 Mbit/s	1.732085 Mbit/s
Bearer channel rate (see note 1)	6.944 Mbit/s	5.216 Mbit/s	3.488 Mbit/s	1.760 Mbit/s
Maximum active subchannels	1 (AS0 only)	1 (AS0 only)	1 (AS0 only)	1 (AS0 only)
Duplex bearers				
Maximum capacity	64 kbit/s	64 kbit/s	64 kbit/s	16 kbit/s
Bearer channel options	C (64 kbit/s)	C (64 kbit/s)	C (64 kbit/s)	C (16 kbit/s)
Maximum active subchannels	1 (LS0)	1 (LS0)	1 (LS0)	1 (LS0) (see note 2)

NOTES
1 The bearer channel rate is equal to the ATM data cell bit rate rounded up to the nearest integer multiple of 32 kbit/s (an ATM cell processor on the network side of the V-interface performs the rate adjustment by inserting idle cells).
2 The 16 kbit/s C channel is carried entirely within the synchronization overhead as described in 6.2; the LS0 sub-channel does not appear as a separate byte within the ADSL frame.

5.4 ADSL system overheads and aggregate bit rates

The aggregate bit rate transmitted by the ADSL system shall include capacity for the following:
- the transported simplex bearer channels;
- the transported duplex bearer channels;
- ADSL system overhead, which includes:
  - capacity for synchronization of the simplex and duplex bearers;
  - synchronization control for the bearers transported with interleaving delay (interleave data buffer) and with no interleaving delay ("fast", or low-latency, data buffer);
  - an ADSL embedded operations channel, eoc (see note);
  - an ADSL overhead control channel, aoc (for on-line adaptation and reconfiguration, as described in clause 13);
  - crc check bytes;
  - fixed indicator bits for OAM (Operations, Administration and Maintenance);
  - FEC redundancy bytes.

NOTES
1. For the downstream simplex bearer rates based on 1.536 Mbit/s, the maximum capacity available to eoc is approximately 23.7 kbit/s for transport classes 1, 2, and 3, and approximately10.7 kbit/s for transport class 4. Actual eoc capacities will depend on the bearer channel rates and the data synchronization implementation.

2. In addition to the digital transport listed in the section, the ADSL shall also permit the transport of POTS as a baseband analog signal.

The organization of all the above data streams into ADSL frames and ADSL superframes shall be as given in 6.2 for the downstream data transmitted and in 7.2 for the upstream data.

The internal overhead channels and their rates shall be as shown in table 9.

Table 9– Internal overhead channel functions and rates

	Downstream rate maximum / minimum / default		**Upstream rate maximum / minimum / default**	
	Transport classes 1, 2, 3, 2M-1, or 2M-2 (minimum and mid range loops)	Transport class 4 or 2M-3 (maximum range loop)	Transport classes 1, 2, 3, 2M-1, or 2M-2 (minimum and mid range loops)	Transport class 4 or 2M-3 (maximum range loop)
Synchronization capacity, shared among all bearers (see note 2)	128 / 64 / 96 kbit/s	96 / 64 / 96 kbit/s (see note 3)	64 / 32 / 64 kbit/s	64 / 32 / 64 kbit/s
Synchronization control and crc, interleave buffer	32 kbit/s	32 kbit/s	32 kbit/s	32 kbit/s
Synchronization control and crc, fast buffer, plus eoc and indicator bits	32 kbit/s	32 kbit/s	32 kbit/s	32 kbit/s
Total	192 / 128 / 160 kbit/s	160 / 128 / 160 kbit/s	128 / 96 / 128 kbit/s	128 / 96 / 128 kbit/s

NOTES
1 The overhead required for FEC is not shown in this table.

2 The shared synchronization capacity includes 32 kbit/s shared among duplex bearers within the interleave buffer, 32 kbit/s shared among bearers within the fast buffer, an additional 32 kbit/s shared with downstream simplex bearers within the interleave buffer, and an additional 32 kbit/s shared with downstream simplex bearers within the fast buffer. The maximum rate occurs when at least one downstream simplex bearer is allocated to each type of buffer; the minimum rate occurs when all bearers are allocated to one buffer type. Default rate allocates bearers according to defaults described in 6.2 and assumes that all optional duplex bearers are implemented.

3 Only one downstream simplex bearer is available in transport class 4 or 2M-3 (maximum range loops); the 64 kbit/s for synchronization of the simplex bearer to ADSL framing can appear in only one of the ADSL buffers (fast or interleaved).

The aggregate transmitted bit rate will depend on the transport class and implementation of optional duplex channels; components of the aggregate transmitted bit rate are summarized in table 10 for downstream transmission and in table 11 for upstream.

Table 10– Determination of aggregate downstream bit rate

	1.536 or 2.048 Mbit/s bearers	**Default bearer channels ($n \times$ 1.536 Mbit/s)**			**Optional bearers based on 2.048 Mbit/s** (see note 1)	
	Transport class 1	Transport class 2 (see note 2)	Transport class 3 (see note 2)	Transport class 4	Transport class 2M-2 (see note 2)	Transport class 2M-3
Total downstream simplex bearer capacity	6.144 Mbit/s	4.608 Mbit/s	3.072 Mbit/s	1.536 Mbit/s	4.096 Mbit/s	2.048 Mbit/s
Duplex C channel	64 kbit/s	64 kbit/s	64 kbit/s	(see note 3)	64 kbit/s	(see note 3)
Total for optional duplex bearers	0, 160, 384, 544 , or 576 kbit/s (see note 4)	0, 160, or 384 kbit/s	0, 160, or 384 kbit/s	0 or 160 kbit/s	0, 160, or 384 kbit/s	0 or 160 kbit/s
Total bearer channel capacity	6.208-6.784 Mbit/s	4.672-5.056 Mbit/s	3.136-3.520 Mbit/s	1.536-1.696 Mbit/s (see note 5)	4.160-4.544 Mbit/s	2.048-2.208 Mbit/s (see note 5)
Overhead range (from table 9)	128 - 192 kbit/s	128 - 192 kbit/s	128 - 192 kbit/s	128 - 160 kbit/s	128 - 192 kbit/s	128 - 160 kbit/s
Aggregate rate range (typical)	6.336-6.976 Mbit/s (6.912 Mbit/s)	4.800-5.248 Mbit/s (5.216 Mbit/s)	3.264-3.712 Mbit/s (3.680 Mbit/s)	1.664-1.856 Mbit/s (1.824 Mbit/s)	4.288-4.736 Mbit/s (4.704 Mbit/s)	2.176-2.368 Mbit/s (2.336 Mbit/s)

NOTES

1 The optional transport class 2M-1 for bearers based on 2.048 Mbit/s has the same combined rates as the default transport class 1.

2 If it is determined that transport classes 2, 3, and 2M-2 can support the 576 kbit/s optional duplex bearer, then the maximum total bearer channel capacity and maximum aggregate rate will increase by 32 kbit/s for these classes.

3 The 16 kbit/s duplex C channel is transported entirely within the overhead dedicated to synchronization capacity.

4 544 kbit/s is required when a 160 kbit/s and a 384 kbit/s optional duplex bearer are both included.

5 The duplex C channel is not included in total bearer channel rates for transport classes 4 and 2M-3; it is included in the overhead.

6 The overhead required for FEC is not shown in this table.

Table 11– Determination of aggregate upstream bit rate

	Transport class 1 or 2M-1	Transport classes 2, 3 or 2M-2 (see note 1)	Transport class 4 or 2M-3
Duplex C channel	64 kbit/s	64 kbit/s	(see note 2)
Total for optional duplex bearers	0, 160, 384, 544, or 576 kbit/s (see note 3)	0, 160, or 384 kbit/s	0 or 160 kbit/s
Total bearer channel capacity	64 - 640 kbit/s	64 - 448 kbit/s	0 - 160 kbit/s
Overhead range (from table 9)	96 - 128 kbit/s	96 - 128 kbit/s	96 - 128 kbit/s
Aggregate rate range (typical)	160 - 768 kbit/s (768 kbit/s)	160 - 576 kbit/s (576 kbit/s)	96 - 288 kbit/s (288 kbit/s)

NOTES

1 If it is determined that Transport Classes 2, 3, and 2M-2 can support the 576 kbit/s optional duplex bearer, then the maximum total bearer channel capacity and maximum aggregate rate will increase by 32 kbit/s for these classes.

2 For Transport Classes 4 and 2M-3, the duplex C channel is 16 kbit/s; this is not included in the total bearer channel rates because it is transported entirely within the overhead dedicated to synchronization capacity.

3 544 kbit/s obtained when both optional duplex bearers are included.

4 The overhead required for FEC is not shown in this table.

5.4.1 Aggregate bit rates for transporting ATM cells

The aggregate transmitted bit rate when an ATM data stream is transported depends on the transport class and allocation of channels to interleaved and non-interleaved data buffers (see 6.2). Components of the aggregate transmitted bit rate are summarized in table 12 .

Table 12– Determination of aggregate bit rate for ATM transport ($n \times 1.536$ Mbit/s $\times$ 53/47 optional bearer channels)

Transport Class	1	2	3	4
Total assigned downstream simplex bearer capacity	6.944 Mbit/s	5.216 Mbit/s	3.488 Mbit/s	1.760 Mbit/s
Duplex C channel	64 kbit/s	64 kbit/s	64 kbit/s	(see note 1)
Total for Optional Duplex Bearers	0 kbit/s	0 kbit/s	0 kbit/s	0 kbit/s
Total Bearer Channel Capacity	7.008 Mbit/s	5.280 Mbit/s	3.552 Mbit/s	1.760 Mbit/s (see note 1)
Overhead Range (from table 9, see Note 2)	128 - 160 kbit/s	128 - 160 kbit/s	128 - 160 kbit/s	128 - 160 kbit/s
Aggregate Rate Range	7.136 to 7.168 Mbit/s	5.408 to 5.440 Mbit/s	3.680 to 3.712 Mbit/s	1.888 to 1.920 Mbit/s

NOTES
1 The duplex C channel is not included in total bearer channel rate for Transport Class 4; it is included in the overhead.
2 Maximum overhead is 160 kbit/s for all transport classes because only one downstream simplex channel is allowed.

5.5 Classification by ATU options

Clause 15.1 describes a further classification, which ties togrther transport payload and loop range based upon whether or not certain options available for the ATU transceivers are used. Category I describes loop ranges and transport payloads using a basic transceiverwith no options required. Category II describes loop ranges and transport payloads using options for trellis coding, power boost, and echo cancellation.

6. ATU-C functional characteristics

6.1 ATU-C input and output V interfaces

The functional data interfaces at the ATU-C are shown in figure 4. Input interfaces for the high-speed downstream simplex bearer channels are designated AS0 through AS3; input/output interfaces for the duplex bearer channels are designated LS0 through LS2. There may also be a duplex interface for operations, maintenance and control of the ADSL system.

The data rates of the input and output data interfaces at the ATU-C for the default configurations are specified in this clause. The data rate at a given interface shall match the rate of the bearer channel configured to that interface.

The total net bearer capacity that can be transmitted in the downstream direction corresponds to the transport class as described in 5.3; the mix of data rates at the downstream simplex input interfaces shall be limited to a combination whose net bit rate does not exceed the net downstream simplex bearer capacity for the given transport class. Similarly, the rate of the duplex bearer at the LS0 interface and the availability of the LS1 and LS2 options shall correspond to the transport class as discussed in 5.3.

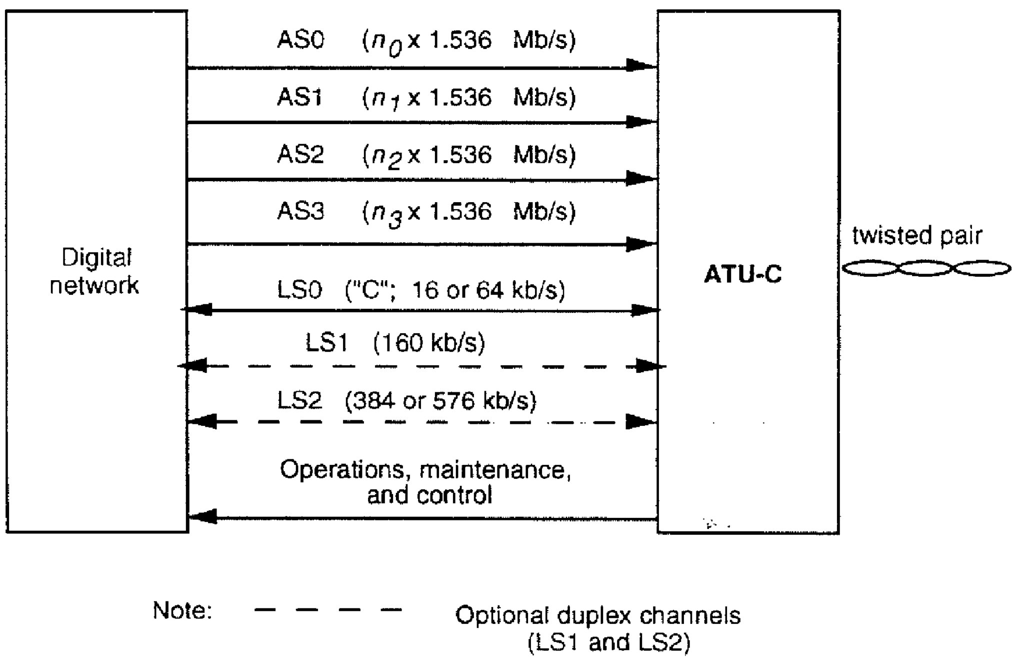


Figure 4 — ATU-C V interfaces (rates for default configuration)

6.1.1 Downstream simplex channels – transmit bit rates

There are four input interfaces at the ATU-C for the high-speed downstream simplex channels based on multiples of 1.536 Mbit/s: AS0, AS1, AS2 and AS3 (ASX in general). The data rates at these interfaces shall be as defined in table 1.

Similarly, there are three interfaces for the optional high-speed downstream simplex channels based on multiples of 2.048 Mbit/s: AS0, AS1, and AS2 (ASX in general). The data rates at these interfaces are defined in table 2.

6.1.2 Transmit and receive bit rates for the duplex channels:

Both input and output data interfaces shall be supplied at the ATU-C for the duplex bearers supported by the ADSL system.

NOTE - Two of the duplex channels are optional, as described in 5.2.2; the rate of the third duplex channel depends on the transport class, as defined in 5.2.1.

Table 13 shows the data rates that shall be supported by both the input and output interfaces at the ATU-C for the duplex channels for the default configurations.

Table 13– Interface data rates for duplex channels (default configurations)

Duplex channel	Data rate
LS0 (see note 1)	16 or 64 kbit/s
LS1 (see note 2)	160 kbit/s
LS2	384 kbit/s or 576 kbit/s
Operations, maintenance, and control	vendor specific

NOTES

1 LS0 is also known as the "C" or control channel. It carries the signaling associated with the ASX data streams and it may also carry some or all of the signaling associated with the other duplex data streams. When LS1 transports ISDN BRA, the signaling for LS1 is contained within the ISDN BRA D channel. If LS1 is used to transport a non-ISDN BRA data stream, then its signaling will also be contained in the C channel.

2 LS1 may be used to carry ISDN BRA. Refer to 6.2.3 for a description of the frame format used within LS1 when it carries this service.

6.1.3 Payload transfer delay

The one-way transfer delay for payload bits in all bearers (simplex and duplex) from the V reference point to the T_{SM} reference point for channels assigned to the fast buffer shall be no more than 2 ms, and for channels assigned to the interleave buffer it shall default to no more than 20 ms. The same requirement applies in the opposite direction, from the T_{SM} reference point to the V reference point.

6.2 Framing

This subclause specifies framing of the downstream signal (ATU-C transmitter). The upstream framing (ATU-R transmitter) is specified in 7.2.

6.2.1 Data symbols

Figure 2 shows a functional block diagram of the ATU-C transmitter with reference points for data framing. Up to four downstream simplex data channels and up to three duplex data channels shall be synchronized to the 4 kHz ADSL DMT symbol rate, and multiplexed into two separate data buffers (fast and interleaved). A cyclic redundancy check (crc), scrambling, and forward error correction (FEC) coding shall be applied to the contents of each buffer separately, and the data from the interleaved buffer shall then be passed through an interleaving function. The two data streams shall then be tone ordered as defined in 6.5, and combined into a data symbol that is input to the constellation encoder. After constellation encoding, the data shall be modulated to produce an analog signal for transmission across the customer loop.

A bit-level framing pattern shall not be inserted into the data symbols of the frame or superframe structure. DMT symbol, or frame, boundaries are delineated by the cyclic prefix inserted by the

modulator (see 6.10). Superframe boundaries are determined by the synchronization symbol, which shall also be inserted by the modulator, and which carries no user data (see 6.9.3).

Because of the addition of FEC redundancy bytes and data interleaving, the data symbols (i.e., bit-level data prior to constellation encoding) have different structural appearance at the three reference points through the transmitter. As shown in figure 2, the reference points for which data framing will be described in the following subclauses are

- A *(Mux data frame):* the multiplexed, synchronized data after the crc has been inserted (synchronization is described in 6.2.2, crc is specified in 6.2.1.3). Mux data frames shall be generated at a nominal 4 kHz rate (i.e., each 250 µsec).
- B *(FEC output data frame):* the data frame generated at the output of the FEC encoder at the DMT symbol rate, where an FEC block may span more than one DMT symbol period.
- C *(constellation encoder input data frame):* the data frame presented to the constellation coder.

6.2.1.1 Superframe structure

ADSL uses the superframe structure shown in figure 5. Each superframe is composed of 68 ADSL data frames, numbered from 0 to 67, which shall be encoded and modulated into DMT symbols, followed by a synchronization symbol, which carries no user or overhead bit-level data and is inserted by the modulator (see 6.9.3) only to establish superframe boundaries. From the bit-level and user data perspective, the DMT symbol rate is 4000 baud (period = 250 µsec), but in order to allow for the insertion of the sync symbol the transmitted DMT symbol rate shall be 69/68 × 4000 baud. Each data frame within the superframe contains data from the fast buffer and the interleaved buffer. The size of each buffer depends on the assignment of bearer channels made during initialization (see 6.2.1 and 12.8.4). (On-line reassignment of bearer channels is for further study.)

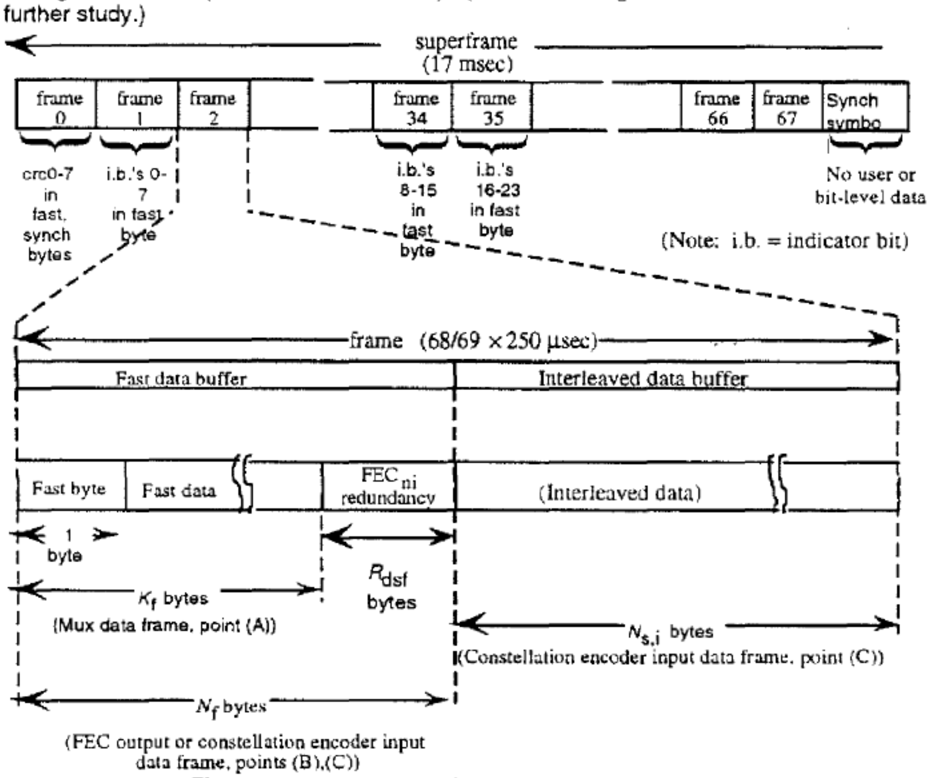


Figure 5 — ADSL superframe structure – ATU-C transmitter

Eight bits per ADSL superframe shall be reserved for the crc on the fast data buffer (crc0-crc7), and 24 indicator bits (ib0-ib23) shall be assigned for OAM functions. As shown in figures 5 and 6, the "fast" byte of the fast data buffer carries the crc check bits in frame 0 and the fixed overhead bit assignments in frames 1, 34, and 35. The "fast" byte in other frames is assigned in even-/odd-frame pairs to either the eoc or to synchronization control of the bearer channels assigned to the fast buffer.

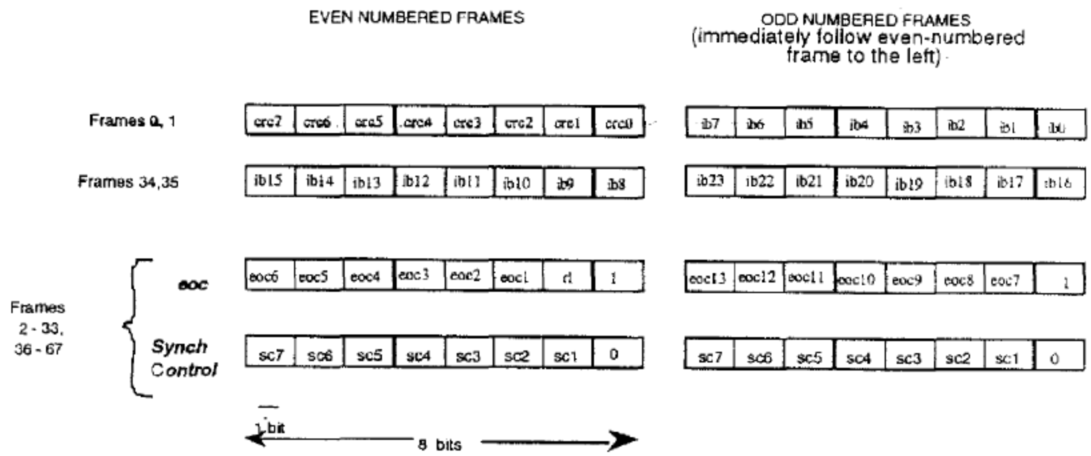


Figure 6 — "Fast" byte format – ATU-C transmitter – fast data buffer

The indicator bits are defined in table 14.

Table 14 – Definition of indicator bits, ATU-C transmitter (fast data buffer, downstream direction)

Indicator bit	Definition
ib0 - ib7	reserved for future use
ib8	febe-i
ib9	fecc-i
ib10	febe-ni
ib11	fecc-ni
ib12	los
ib13	rdi
ib14 - ib23	reserved for future use
NOTE - See clause 11 for definitions of the bits and their use.	

If bit 0 of the "fast" byte in an even-numbered frame (other than frames 0 and 34) is "1", then the "fast" byte of that frame and the odd-numbered frame that immediately follows is used to carry a 13-bit "eoc frame", which is defined in table 15, and on additional bit, r1, which is reserved for future use (set to 1 until assigned otherwise).

Table 15– eoc frame structure

Bit designation	eoc bit allocation
eoc1, eoc2	Address (11 = ATU-C, 00 = ATU-R, 01 and 10 reserved)
eoc3	Data/message indicator bit: "0" = information field contains op code for ADSL eoc message, "1" = information field contains binary or ASCII data.
eoc4	Odd ("1") / Even ("0") byte indicator for multibyte transmission in data read or write mode
eoc5	Autonomous ATU-R message indicator bit (see note): "0" = autonomous ATU-R message, "1" = ATU-R response to current eoc protocol state.
eoc6 - eoc13	Information field.
NOTE - The only autonomous message currently defined for the ATU-R is the "dying gasp" (11.1.4.4). Other uses of the eoc5 bit are for further study.	

The eoc protocol and message formats are described in 11.1.

Bit 0 of the "fast" byte in an even-numbered frame (other than frames 0 and 34) shall be set to "0", to indicate that the "fast" bytes of that frame and the odd-numbered frame that immediately follows are used for synchronization control within their respective frames (the "fast" byte format for synch control is described in 6.2.2.1).

Eight bits per ADSL superframe shall be used for the crc on the interleaved data buffer (crc0 - crc7). As shown in figures 6 and 7, the "synch" byte of the interleaved data buffer carries the crc check bits for the previous superframe in frame 0. In all other frames (1 through 67), the "synch" byte shall be used for synchronization control of the bearer channels assigned to the interleaved data buffer, or to carry an ADSL overhead control (aoc) channel. When any bearer data streams appear in the interleave buffer, then the aoc data shall be carried in the LEX byte, and the "synch" byte shall designate when the LEX byte contains aoc data and when it contains data bytes from the bearer data streams. When no bearer data streams are allocated to the interleave data buffer, i.e., all $B_I(ASX) = B_I(LSX) = 0$, then the "synch" byte shall carry the aoc data directly (AEX and LEX bytes, described in 6.2.1.2, do not exist in the interleave buffer in this case). The format of the "synch" byte is described in 6.2.2.2.

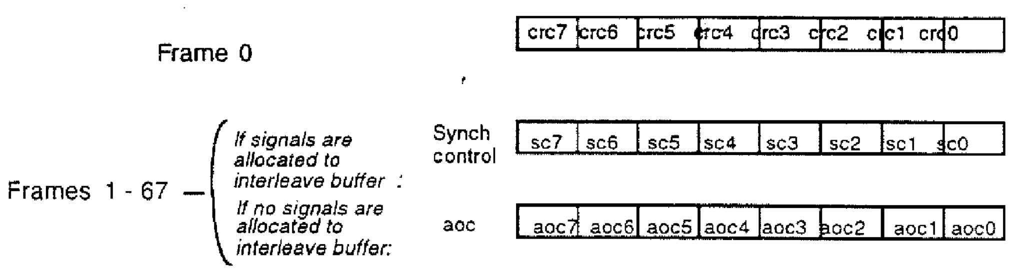


Figure 7 — "Synch" byte format – ATU-C transmitter – Interleaved data buffer

6.2.1.2 Frame structure

Each frame of data shall be encoded into a multicarrier symbol, as described in 6.3 through 6.6. As is shown in figure 2, each frame is composed of a fast data buffer and an interleaved data

buffer, and the frame structure has a different appearance at each of the reference points (A, B, and C). The bytes of the fast buffer shall be clocked into the constellation encoder first, followed by the bytes of the interleaved data buffer. Bytes are clocked least significant bit first.

Each user data stream shall be assigned to either the fast or the interleaved buffer during initialization (see 12.6.1), and a pair of bytes, $[B_F, B_I]$, shall be transmitted for each data stream, where B_F and B_I designate the number of bytes allocated to the fast and interleaved buffers, respectively.

The seven possible $[B_F,B_I]$ pairs to specify the downstream bearer channel rates are

- B_F(ASX), B_I(ASX) for X = 0, 1, 2 and 3, for the downstream simplex channels;
- B_F(LSX), B_I(LSX) for X = 0, 1 and 2, for the (downstream transport of the) duplex channels.

The rules for allocation are:

- for any data stream, X, except the 16 kbit/s C channel option, either B_F(X) = the data rate (in kbit/s) of the fast buffer and B_I (X) = 0, or B_F(X) = 0 and B_I(X) = the data rate (in kbit/s) of the interleaved buffer;

- for the 16 kbit/s C channel option, B_F(LS0) = 255 (binary 11111111) and B_I(LS0) =0, or B_F(LS0) = 0 and B_I(LS0) = 255.

Configurations (i.e., sets of $[B_F, B_I]$) for the four possible transport classes are given in table 16 for the default configuration (bearers based on 1.536 Mbit/s), and in table 17 for the three possible transport classes for the bearer channel optional rates based on 2.048 Mbit/s.

On-line reconfiguration (e.g., changing the mix of data channel rates or re-allocation of user data streams between fast and interleaved data buffers, or both) is for further study.

Table 16 – Default fast and interleaved data buffer allocations for ATU-C transmitter – Configurations for bearers based on multiples of 1.536 Mbit/s

Signal	B_I (Interleaved data buffer)				B_F (fast data buffer)			
	Transport class 1	Transport class 2	Transport class 3	Transport class 4	Transport class 1	Transport class 2	Transport class 3	Transport class 4
AS0	96	96	48	48	0	0	0	0
AS1	96	48	48	0	0	0	0	0
AS2	0	0	0	0	0	0	0	0
AS3	0	0	0	0	0	0	0	0
LS0	2	2	2	255 (see note)	0	0	0	0
LS1	0	0	0	0	5	0	0	5
LS2	0	0	0	0	12	12	12	0

NOTE - For loop transport class 4, B_F(LS0) = 255 or B_I(LS0) = 255 indicates a 16 kbit/s C channel, which is carried entirely within the synchronization control overhead (LEX byte) as described in 6.2.2; thus, the LS0 sub-channel does not appear as a separate byte within the ADSL frame.

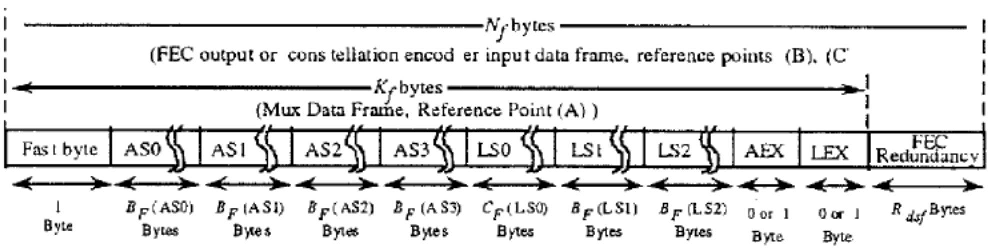
Table 17 – Default fast and interleaved data buffer allocations for ATU-C transmitter – Optional configurations for bearers based on multiples of 2.048 Mbit/s

Signal	B_I (Interleaved data buffer)			B_F (fast data buffer)		
	Transport class 2M-1	Transport class 2M-2	Transport class 2M-3	Transport class 2M-1	Transport class 2M-2	Transport class 2M-3
AS0	64	64	64	0	0	0
AS1	64	64	0	0	0	0
AS2	64	0	0	0	0	0
LS0	2	2	255 (see note)	0	0	0
LS1	0	0	0	5	0	5
LS2	0	0	0	12	12	0

NOTE - For transport class 2M-3, B_F(LS0) = 255 or B_I(LS0) = 255 indicates a 16 kbit/s C channel, which is carried entirely within the synchronization control overhead (LEX byte) as described in 6.2.2; thus, the LS0 sub-channel does not appear as a separate byte within the ADSL frame.

6.2.1.2.1 Fast data buffer

The frame structure of the fast data buffer shall be as shown in figure 8 for the three reference points that are defined in figure 2.



$$K_f = 1 + \sum_{i=0}^{3} B_F(AS_i) + A_F + \sum_{j=0}^{2} B_F(LS_j) + L_F,$$

$$\text{where } A_F = \begin{cases} 0, & \sum_{i=0}^{3} B_F(AS_i) = 0, \\ 1 & \text{otherwise.} \end{cases}$$

$$\text{and } L_F = \begin{cases} 0, & \sum_{i=0}^{3} B_F(AS_i) = \sum_{j=0}^{2} B_F(LS_j) = 0, \\ 1 & \text{otherwise.} \end{cases}$$

$$C_F(LS0) = \begin{cases} 0, & B_F(LS0) = 255 \text{ (Binary 11111111)}, \\ B_F(LS0) & \text{otherwise.} \end{cases}$$

$$N_f = K_f + R_{dsf},$$

where R_{dsf} = # FEC Redundancy Bytes.

Note – $L_F = 1$ when $B_F(LS0) = 255$

Figure 8 – Fast data buffer – ATU-C transmitter

At reference point A (Mux data frame) in figure 2, the fast buffer shall always contain at least the "fast" byte. This is followed by B_F(AS0) bytes of channel AS0, then B_F(AS1) bytes of channel AS1, B_F(AS2) bytes of channel AS2 and B_F(AS3) bytes of channel AS3. Next come the bytes

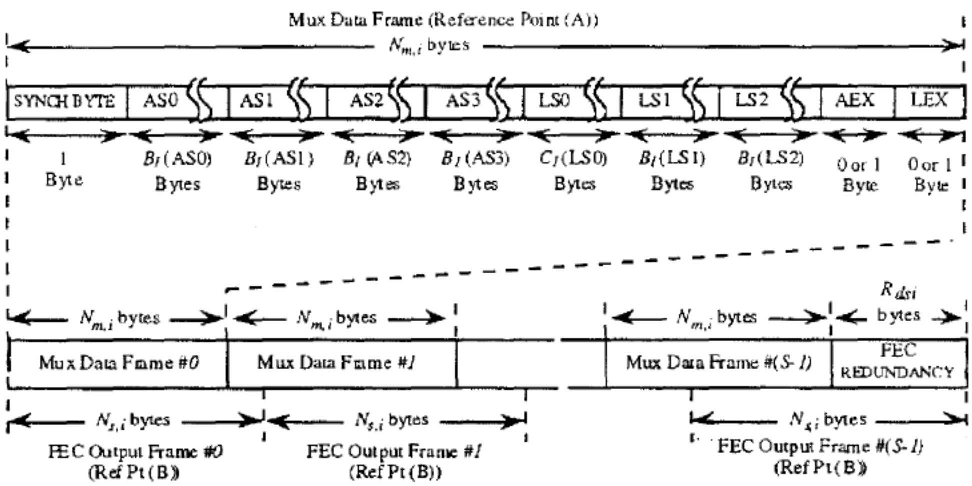
for any duplex (LSX) channels allocated to the fast buffer. If any B_F(ASX) is non-zero, then both an AEX and an LEX byte follow the bytes of the last LSX channel, and if any B_F(LSX)is non-zero, the LEX byte shall be included.

Note that when B_F(LS0) = 255, no bytes are included for the LS0 channel. Instead, the 16 kbit/s C channel shall be transported in every other LEX byte on average, using the synch byte to denote when to add the LEX byte to the LS0 data stream.

R_{dsf} FEC redundancy bytes shall be added to the mux data frame (reference point A) to produce the FEC output data frame (reference point B), where R_{dsf} is given in the RATES1 options used during initialization. For the default configurations given in tables 16 and 17 R_{dsf} = 4; for other configuration options, the value shall be given to the ATU-C in some manner (for example, via a host control port). When no data streams are allocated to the fast buffer R_{dsf} = 0 (no FEC redundancy bytes are added). Because the data from the fast buffer is not interleaved, the constellation encoder input data frame (reference point C) is identical to the FEC output data frame (reference point B).

6.2.1.2.2 Interleaved data buffer

The frame structure of the interleaved data buffer is shown in figure 9 for reference points A and B, which are defined in figure 2 .



$$N_{m,i} = 1 + \sum_{i=0}^{3} B_I(AS_i) + A_I + \sum_{j=0}^{2} B_I(LS_j) + L_I,$$

where $A_I = \begin{cases} 0, & \sum^{3} B_I(AS_i) = 0, \\ 1 & \text{otherwise}, \end{cases}$

and

$$L_I = \begin{cases} 0, & \sum_{i=0}^{3} B_I(AS_i) = \sum_{j=0}^{2} B_I(LS_j) = 0, \\ 1 & \text{otherwise}. \end{cases}$$

(Note: $L_I = 1$ when $B_I(LS0) = 255$)

$$C_I(LS0) = \begin{cases} 0, & B_I(LS0) = 255 \text{ (Binary 11111111)}, \\ B_I(LS0) & \text{otherwise}. \end{cases}$$

$$N_{s,i} = (S * N_{m,i} + R_{dsi}) / S,$$

where R_{dsi} = # FEC Redundancy Bytes,
and S = # DMT symbols per FEC codeword.

Figure 9 — Interleaved data buffer, ATU-C transmitter

At reference point A, the Mux data frame, the interleaved data buffer shall always contain at least the "synch" byte. The rest of the buffer shall be built in the same manner as the fast buffer, substituting B_I in place of B_F. The length of each mux data frame is $N_{m,i}$ bytes, as defined in figure 9.

The FEC coder shall take in S mux data frames and append R_{dsi} FEC redundancy bytes to produce the FEC codeword of length $N_{FEC,i} = S \times N_{m,i} + R_{dsi}$ bytes. The FEC output data frames shall contain $N_{s,i} = N_{FEC,i} / S$ bytes, where $N_{s,i}$ is an integer. When $S > 1$, then for the S frames in an FEC codeword, the FEC output Data Frame (reference point B) shall partially overlap two mux data frames for all except the last frame, which shall contain the R_{dsi} FEC redundancy bytes.

The FEC output data frames are interleaved to a specified interleave depth. The interleaving process (see 6.4.2) delays each byte of a given FEC output data frame a different amount, so that the constellation encoder input data frames will contain bytes from many different FEC data frames. At reference point A in the transmitter, mux data frame 0 of the interleaved data buffer is aligned with the ADSL superframe and mux data frame 0 of the fast data buffer (this is not true at reference point C). At the receiver, the interleaved data buffer will be delayed by $S \times$ interleave depth $\times$ 250 msec (16 msec for the defaults given in tables 18 and 19) with respect to the fast data buffer, and frame 0 (containing the crc bits for the interleaved data buffer) will appear a fixed number of frames after the beginning of the receiver superframe.

The FEC coding overhead, the number of symbols per FEC codeword, and the interleave depth are listed in tables 18 and 19 for the default configurations (i.e., for all ASX signals plus LS0 allocated to the interleave buffer) in tables 16 and 17. These defaults correspond to the default data rates. For other rates and configurations, the coding parameters shall be given to the ATU-C in some manner (for example, via a host control port).

Table 18 – Default FEC coding parameters and interleave depth for ATU-C transmitter – Default configurations for bearers based on multiples of 1.536 Mbit/s

Transport class	R_{dsi} (FEC redundancy bytes)	S (symbols per codeword)	Interleave depth (FEC codewords)
Transport class 1	16	1	64
Transport class 2	12	1	64
Transport class 3	16	2	32
Transport class 4	16	4	16
Synch byte only	4	4	16

Table 19– Default FEC coding parameters and interleave depth for ATU-C transmitter – Optional configurations for bearers based on multiples of 2.048 Mbit/s

Transport class	R_{dsi} (FEC redundancy bytes)	S (symbols per codeword)	Interleave depth (FEC codewords)
2M-1	16	1	64
2M-2	12	1	64
2M-3	12	2	32

6.2.1.3 Cyclic redundancy check (crc)

Two cyclic redundancy checks (crc's)—one for the fast data buffer and one for the interleaved data buffer–are generated for each superframe and transmitted in the first frame of the following superframe. Eight bits per buffer type (fast or interleaved) per superframe are allocated to the crc check bits. These bits are computed from the k message bits using the equation:

$$\text{crc}(D) = M(D)\, D^8 \text{ modulo } G(D),$$

where:

$M(D) = m_0 D^{k-1} \oplus m_1 D^{k-2} \oplus .... \oplus m_{k-2} D \oplus m_{k-1}$, is the message polynomial

$G(D) = D^8 \oplus D^4 \oplus D^3 \oplus D^2 \oplus 1$, is the generating polynomial,

$\text{crc}(D) = c_0 D^7 \oplus c_1 D^6 \oplus ..... \oplus c_6 D \oplus c_7$, is the check polynomial,

$\oplus$ indicates modulo-2 addition (exclusive-or)

and D is the delay operator.

That is, crc is the remainder when $M(D)\, D^8$ is divided by G.

The crc check bits are transported in the "fast byte" (8 bits) of frame 0 in the fast data buffer. and the "synch byte"
(8 bits) of frame 0 in the interleaved data buffer.

The bits covered by the crc include

- fast data buffer:
  - *frame 0:* ASX bytes ($X = 0, 1, 2, 3$), LSX bytes ($X = 0, 1, 2$), followed by any AEX and LEX bytes.
  - *all other frames:* "fast" byte, followed by ASX bytes ($X = 0, 1, 2, 3$), LSX bytes ($X = 0, 1, 2$), and any AEX and LEX bytes.
- interleaved data buffer:
  - *frame 0:* ASX bytes ($X = 0, 1, 2, 3$), LSX bytes ($X = 0, 1, 2$), followed by any AEX and LEX bytes.
  - *all other frames:* "synch" byte, followed by ASX bytes ($X = 0, 1, 2, 3$), LSX bytes ($X = 0, 1, 2$), and any AEX and LEX bytes.

Each byte shall be clocked into the crc least significant bit first.

The crc field length will vary with the allocation of bytes to the fast and interleaved data buffers (the numbers of bytes in ASX and LSX vary according to the [B_F, B_I] pairs; AEX is present in a given buffer only if at least one ASX is allocated to that buffer; LEX is present in a given buffer only if at least one ASX or one LSX is allocated to that buffer).

Because of the flexibility in assignment of bearer channels to the fast and interleaved data buffers, crc field lengths over an ADSL superframe will vary from approximately 530 bits to approximately 119,000 bits.

6.2.2 Synchronization

The input data streams are synchronized to the ADSL clock using the synchronization control byte and the AEX and LEX bytes. Forward-error-correction coding shall always be applied to the synchronization control byte(s).

6.2.2.1 Synchronization for the fast data buffer

Synchronization control for the fast data buffer can occur in frames 2 through 33 and 36 through 67 of an ADSL superframe as described in 6.2.1.1, where the "fast" byte may be used as the synchronization control byte.

The format of the "fast" byte when used as synchronization control for the fast data buffer is given in table 20.

Table 20 - Fast byte format

Bits	Designation	Codes
sc7, sc6	ASX channel designator	"00" : channel AS0 "01" : channel AS1 "10" : channel AS2 "11" : channel AS3
sc5, sc4	Synchronization control for the designated ASX channel	"00" : do nothing "01" : add AEX byte to designated ASX channel "11" : add AEX and LEX bytes to ASX channel "10" : delete last byte from designated ASX channel
sc3, sc2	LSX channel designator	"00" : channel LS0 "01" : channel LS1 "10" : channel LS2 "11" : no synchronization action; if sc5, sc4 is not equal to "11", LEX may carry LS2 "start of frame" verification pointer (see 6.2.4)
sc1	Synchronization control for the designated LSX channel	"1" : add LEX byte to designated LSX channel "0" : delete last byte from designated LSX channel
sc0	Synch/eoc designator	"0" : perform synchronization control as indicated in sc7-sc1 "1" : this byte of current (even-numbered) frame and of frame that immediately follows is an eoc frame

No synchronization action shall be taken for those frames for which the "fast" byte is used for crc, fixed indicator bits, or eoc.

NOTES

1 ADSL deployments may need to interwork with DS1 (1.544 Mbit/s) or DS1C (3.152 Mbit/s) rates. The synchronization control option that allows adding up to two bytes to an ASX bearer channel provides sufficient overhead capacity to transport combinations of DS1 or DS1C channels transparently (without interpreting or stripping and regenerating the framing embedded within the DS1 or DS1C). The synchronization control algorithm shall, however, guarantee that the fast byte in some minimum number of frames is available to carry eoc frames, so that a minimum eoc rate (4 kbit/s) may be maintained.

2 When the data rate of the C channel is 16 kbit/s, the LS0 sub-channel is transported in the LEX byte, using the "add LEX byte to designated LSX channel", with LS0 as the designated channel, every other frame on average.

6.2.2.2 Synchronization for the interleaved data buffer

Synchronization control for the interleaved data buffer can occur in frames 1 through 67 of an ADSL superframe as described in 6.2.1.1, where the "synch" byte may be used as the synchronization control byte.

The format of the "synch" byte when used as synchronization control for the interleaved data buffer shall be as given in table 21. In the case where no signals are allocated to the interleaved data buffer, the "synch" byte shall carry the aoc data directly, as shown in figure 17 in 6.2.1.1.

Table 21 – Synch byte format – Interleaved data buffer

Bits	Designation	Codes
sc7, sc6	ASX channel designator	"00" : channel AS0 "01" : channel AS1 "10" : channel AS2 "11" : channel AS3
sc5, sc4	Synchronization control for the designated ASX channel	"00" : do nothing "01" : add AEX byte to designated ASX channel "11" : add AEX and LEX bytes to ASX channel "10" : delete last byte from designated ASX channel
sc3, sc2	LSX channel designator	"00" : channel LS0 "01" : channel LS1 "10" : channel LS2 "11" : do nothing to any LSX channel
sc1	Synchronization control for the designated LSX channel	"1" : add LEX byte to designated LSX channel "0" : delete last byte from designated LSX channel
sc0	Synch/aoc designator	"0" : perform synchronization control as indicated in sc7-sc1 "1" : LEX byte carries ADSL overhead control channel data; synchronization control may be allowed for "add AEX" or "delete" as indicated in sc7-sc1

No synchronization action shall be taken during frame 0, where the "synch" byte is used for crc, and the LEX byte carries the aoc.

NOTES
1 ADSL deployments may need to interwork with DS1 (1.544 Mbit/s) or DS1C (3.152 Mbit/s) rates. The synchronization control option that allows adding up to two bytes to an ASX bearer channel provides sufficient overhead capacity to transport combinations of DS1 or DS1C channels transparently (without interpreting or stripping and regenerating the framing embedded within the DS1 or DS1C).
2 When the data rate of the C channel is 16 kbit/s, the LS0 sub-channel is transported in the LEX byte, using the "add LEX byte to designated LSX channel", with LS0 as the designated channel, every other frame on average.

6.2.3 Frame format of ISDN basic access over LS1

When the LS1 channel transports ISDN Basic Access, the framing for this channel shall be a binary equivalent of the frame structure specified for information flow across the ISDN Basic Access Interface point, as specified in ANSI T1.601-1992.

This frame structure within the LS1 channel may be fixed in state SL3 for the downstream direction, and in state SN3 for the upstream direction. During states where the network, or NT1 is not ready, (as generally conveyed by the *act* bit set to 0), the 2B+D fields shall be set to all ones before scrambling. If the ATU is unable to provide SN3 or SL3, then the LS1 channel bytes shall be filled with all ones. State definitions for SN3, SL3, and the *act* bit are specified in ANSI T1.601-1992.

The ISDN Basic Access maintenance definitions and positions, as prescribed by ANSI T1.601-1992, shall retain their definitions across the LS1 channel.

6.2.4 Framing for 384 / 576 kbit/s applications over LS2 (optional)

When the LS2 channel transports 384 or 576 kbit/s applications that require frame integrity, and the LS2 channel is allocated to the non-interleaved data buffer, the ADSL system may, as an option, provide byte and frame integrity of the bearer service channel.

If this option is provided, the ADSL system shall provide byte integrity by mapping the bearer service channel's bytes into ADSL sub-channel LS2 bytes (i.e., mapping bytes across the V- and T-interfaces).

The ADSL system shall provide frame integrity by

- transmitting a non-zero value for the LS2 frame-size parameter during initialization to indicate to the receiver that the LS2 channel should provide frame integrity;
- locally generating framing indication at the receiver, and passing this framing along with the LS2 data stream to the service module at the CI or to the network at the network side of the ADSL link;
- transmitting a frame verification pointer when certain conditions allow across the "U" Interface;
- statistically verifying the bearer service channel framing to the locally-generated framing indication at the receiver.

The LS2 frame-size parameter, FS(LS2), shall be in bytes per (bearer service) frame. For example, for 384 kbit/s service:

- B_F(LS2) = 384 kbit/s / (32 kbit/s/byte/ADSL frame) = 12 bytes per ADSL frame;

- FS(LS2) = 384 kbit/s / (64 kbit/s/byte/bearer service frame) = 6 bytes per bearer service frame.

FS(LS2) shall be set to zero (0) to indicate that framing is not required for the service transported by ADSL sub-channel LS2, or that the transmitter does not provide this option. In either case, no frame verification pointers will be sent by the transmitter.

The ATU-C transmitter may transmit a frame verification pointer when all of the following conditions are satisfied:

a) LS2 is allocated to the fast data buffer;
b) the LS2 frame size is non-zero;
c) no synchronization action is required on any of the ADSL LSX sub-channels in the current frame;
d) the LEX byte is not used for "add 2" synchronization for any of the ADSL ASX sub-channels in the current frame;
e) the transmitter has a valid verification pointer value available for the current frame.

NOTES

1 Condition (c) is satisfied when bits sc3, sc2 (table 21) in the fast byte of frames 2 through 33 or 36 through 67 are "11" and bit sc0 is "0", or the fast byte of the current frame carries crc or indicator bits (i.e., frame numbers 0, 1, 34, and 35).

2 Condition (d) is satisfied when bits sc5, sc4 in the fast byte of frames 2 through 33 or 37 through 67 are "00", "01", or "10" and bit sc0 is "0".

3 The transmitter is not required to transmit a verification pointer in all frames that satisfy conditions (c) and (d).

The frame verification pointer, when transmitted, shall be placed in the LEX byte and shall contain the number of the byte within the current frame's LS2 sub-channel that is the first byte of a bearer service frame, with the first byte of the LS2 sub-channel being byte number zero (0).

When conditions (a) through (d) above are satisfied but the transmitter does not have a verification pointer value to insert, the LEX byte shall be filled with binary 1's to indicate that it does not contain a verification pointer. The receiver shall use the verification pointer only when it falls within a valid range for the configured LS2 rate (i.e., 0 through [B_F(LS2)-1]).

6.3 Scramblers

The binary data streams output from the fast and interleaved buffers shall be scrambled separately using the following algorithm for both:

$$d_n' = d_n \oplus d_{n-18}' \oplus d_{n-23}'$$

where d_n is the n-th output from the fast or interleaved buffer (i.e., input to the scrambler), and d_n' is the n-th output from the corresponding scrambler.

These scramblers shall be applied to the serial data streams without reference to any framing or symbol synchronization. Descrambling in receivers can likewise be performed independent of symbol synchronization.

6.4 Forward error correction

6.4.1 Reed-Solomon coding

R (i.e., R_{dsf} or R_{dsi}) redundant check bytes c_0, c_1, ..., c_{R-2}, c_{R-1} shall be appended to K message bytes m_0, m_1, ..., m_{K-2}, m_{K-1} to form a Reed-Solomon code word of size $N = K + R$ bytes. The check bytes are computed from the message byte using the equation:

$$C(\mathrm{D}) = M(\mathrm{D})\,\mathrm{D}^R \text{ modulo } G(\mathrm{D})$$

where:

$$M(\mathrm{D}) = m_0\,\mathrm{D}^{K-1} \oplus m_1\,\mathrm{D}^{K-2} \oplus \ldots \oplus m_{K-1}\,\mathrm{D} \oplus m_K \text{ is the message polynomial,}$$

$$C(\mathrm{D}) = c_0\,\mathrm{D}^{R-1} \oplus c_1\,\mathrm{D}^{R-2} \oplus \ldots \oplus c_{R-2}\,\mathrm{D} \oplus c_{R-1} \text{ is the check polynomial,}$$

and $G(\mathrm{D}) = \prod (\mathrm{D} \oplus \mathrm{a}^i)$ is the generator polynomial of the Reed-Solomon code, where the index of the product runs from $i = 0$ to R-1. That is, C(D) is the remainder obtained from dividing M(D) D^R by G(D). The arithmetic is performed in the Galois Field GF(256), where a is a primitive element that satisfies the primitive binary polynomial $x^8 \oplus x^4 \oplus x^3 \oplus x^2 \oplus 1$. A data byte ($d_7$, d_6, ..., d_1, d_0) is identified with the Galois Field element $d_7\mathrm{a}^7 \oplus d_6\mathrm{a}^6 \oplus \ldots \oplus d_1\mathrm{a} \oplus d_0$

The number of check bytes *R*, and the codeword size *N* vary, as explained in 6.2 .

6.4.2 Interleaving

The Reed-Solomon codewords in the interleave buffer shall be convolutionally interleaved. The interleaving depth varies, as explained in 6.2, but it shall always be a power of 2. Convolutional interleaving is defined by the rule:

> Each of the *N* bytes B_0, B_1, ..., B_{N-1} in a Reed-Solomon codeword is delayed by an amount that varies linearly with the byte index. More precisely, byte B_i (with index i) is delayed by (D-1) * i bytes, where D is the interleave depth.

An example for $N = 5$, $D = 2$ is shown in table 22, where B^j_i denotes the i-th byte of the j-th codeword.

Table 22 – Convolutional interleaving example for $N = 5$, $D = 2$

Inter-leaver input	B^j_0	B^j_1	B^j_2	B^j_3	B^j_4	B^{j+1}_0	B^{j+1}_1	B^{j+1}_2	B^{j+1}_3	B^{j+1}_4
Inter-leaver output	B^j_0	B^{j-1}_3	B^j_1	B^{j-1}_4	B^j_2	B^{j+1}_0	B^j_3	B^{j+1}_1	B^j_4	B^{j+1}_2

With the above-defined rule, and the chosen interleaving depths (powers of 2), the output bytes from the interleaver always occupy distinct time slots when *N* is odd. When *N* is even, a dummy byte shall be added at the beginning of the codeword at the input to the interleaver. The resultant odd-length codeword is then convolutionally interleaved, and the dummy byte then removed from the output of the interleaver.

6.5 Tone ordering

A DMT time-domain signal has a high peak-to-average ratio (its amplitude distribution is almost Gaussian), and large values may be clipped by the digital-to-analog converter. The error signal caused by clipping can be considered as an additive negative impulse for the time sample that was clipped. The clipping error power is almost equally distributed across all tones in the symbol in which clipping occurs. Clipping is therefore most likely to cause errors on those tones that, in anticipation of higher received SNRs, have been assigned the largest number of bits (and therefore have the densest constellations). These occasional errors can be reliably corrected by the FEC coding if the tones with the largest number of bits have been assigned to the interleave buffer.

The numbers of bits and the relative gains to be used for every tone are calculated in the ATU-R receiver, and sent back to the ATU-C according to a defined protocol (see 12.9.8) The pairs of numbers are typically stored, in ascending order of frequency or tone number *i*, in a bit and gain table.

The "tone-ordered" encoding shall assign the first B_F bytes ($8B_F$ bits) from the symbol buffer (see 6.2) to the tones with the smallest number of bits assigned to them, and the remaining B_I bytes ($8B_I$ bits) to the remaining tones.

The ordered bit table b'_i shall be based on the original bit table b_i as follows:

For $k = 0$ to 15
  From the bit table, find the set of all i with the number of bits per tone $b_i = k$
  Assign b_i to the ordered bit allocation table in ascending order of i

A complementary de-ordering procedure should be performed in the ATU-R receiver. It is not necessary, however, to send the results of the ordering process to the receiver because the bit table was originally generated in the ATU-R, and therefore that table has all the information necessary to perform the de-ordering.

6.6 Constellation encoder – with trellis coding

Block processing of Wei's 16-state 4-dimensional trellis code is optional to improve system performance. An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to $N_{downmax}$ (≤ 15).

6.6.1 Bit extraction

Data bytes from the DMT symbol buffer shall be extracted according to a re-ordered bit allocation table b'_i, least significant bit first. Because of the 4-dimensional nature of the code, the extraction is based on pairs of consecutive b'_i, rather than on individual ones, as in the non-trellis-coded case. Furthermore, due to the constellation expansion associated with coding, the bit allocation table specifies b'_i, the number of coded bits per tone, which can be any integer from 2 to 15. Given a pair (x,y) of consecutive b'_i, $x+y-1$ bits (reflecting a constellation expansion of 1 bit per 4 dimensions, or one half bit per tone) are extracted from the DMT symbol buffer. These $z = x+y-1$ bits ($t_z, t_{z-1}, \ldots, t_1$) are used to form the binary word u as shown in table 23. The tone ordering procedure ensures $x \leq y$. Single-bit constellations are not allowed because they can be replaced by 2-bit constellations with the same average energy. Refer to 6.6.2 for the reason behind the special form of the word u for the case $x = 0$, $y > 1$.

Table 23 - Forming the binary word *u*

Condition	Binary word / comment
$x > 1$, $y > 1$	$u = (t_z, t_{z-1}, \ldots, t_1)$
$x = 1$, $y \geq 1$	Condition not allowed
$x = 0$, $y > 1$	$u = (t_z, t_{z-1}, \ldots, t_2, 0, t_1, 0)$
$x = 0$, $y \leq 1$	Bit extraction not necessary, no message bits being sent

The last two 4-dimensional symbols in the DMT symbol shall be chosen to force the constellation state to the zero state. For each of these symbols, the 2 LSBs of u are pre-determined, and only $x+y-3$ bits are extracted from the DMT symbol buffer.

6.6.2 Bit conversion

The binary word $u = (u_{z'}, u_{z'-1}, \ldots, u_1)$ determines two binary words $v = (v_{z'-y}, \ldots, v_0)$ and $w = (w_{y-1}, \ldots, w_0)$, which are used to look up two constellation points in the encoder constellation table. For the usual case of x >1 and $y > 1$, $z' = z = x+y-1$, and v and w contain x and y bits respectively. For the special case of $x = 0$ and $y > 0$, $z' = z+2 = y+1$, $v = (v_1, v_0) = 0$ and $w = (w_{y-1}, \ldots, w_0)$. The bits (u_3, u_2, u_1) determine (v_1, v_0) and (w_1, w_0) according to figure 10.

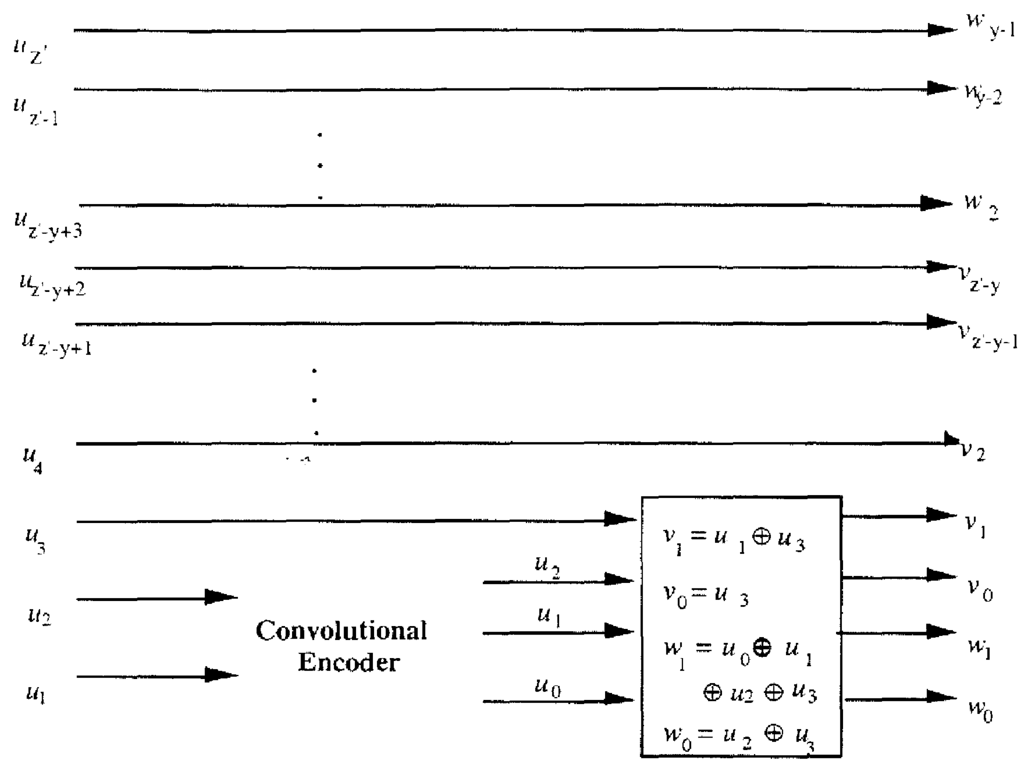


Figure 10 — Conversion of *u* to *v* and *w*

The convolutional encoder shown in figure 10 is a systematic encoder (i.e. u_1 and u_2 are passed through unchanged) as shown in figure 11. The states (S_3, S_2, S_1, S_0) are used to label the states of the trellis shown in figure 13. At the beginning of a DMT symbol period the states are initialized to (0, 0, 0, 0).

The remaining bits of v and w are obtained from the less significant and more significant parts of ($u_{z'}$, $u_{z'-1}$, .. . u_4), respectively. When x >1 and y > 1, v = ($u_{z'-y+2}$, $u_{z'-y+1}$, ..., u_4, v_1, v_0) and w = ($u_{z'}$, $u_{z'-1}$, ..., $u_{z'-y+3}$, w_1, w_0). The bit extraction and conversion algorithms have been judiciously designed so that when x = 0, v_1 = v_0 = 0.

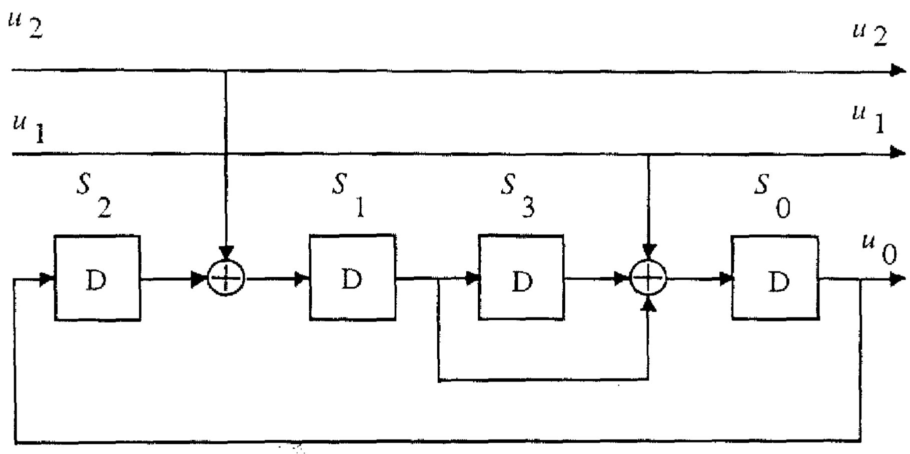


Figure 11 — Finite state machine for Wei's encoder

In order to force the final state to the zero state (0,0,0,0), the 2 LSBs u_1 and u_2 of the final two 4-dimensional symbol in the DMT symbol are constrained to $u_1 = S_1 = S_3$, and $u_2 = S_2$.

6.6.3 Coset partition and trellis diagram

In a trellis code modulation system, the expanded constellation is labeled and partitioned into subsets ("cosets") using a technique called mapping by set-partitioning. The four-dimensional cosets in Wei's code can each be written as the union of two Cartesian products of two 2-dimensional cosets. For example, $C_4^0 = (C_2^0 \times C_2^1) \cup (C_2^2 \times C_2^3)$. The four constituent 2-dimensional cosets, denoted by C_2^0, C_2^1, C_2^2, C_2^3, are shown in figure 12.

1	3	1	3	1	3	1	3
0	2	0	2	0	2	0	2
1	3	1	3	1	3	1	3
0	2	0	2	0	2	0	2
1	3	1	3	1	3	1	3
0	2	0	2	0	2	0	2
1	3	1	3	1	3	1	3
0	2	0	2	0	2	0	2

Figure 12 — Constituent 2-dimensional cosets for Wei's code

The encoding algorithm ensures that the 2 least significant bits of a constellation point comprise the index i of the 2-dimensional coset C_2^i in which the constellation point lies. The bits (v_1, v_0) and (w_1, w_0) are in fact the binary representations of this index._

The three bits (u_2, u_1, u_0) are used to select one of the 8 possible four-dimensional cosets. The 8 cosets are labeled C_4^i where i is the integer with binary representation (u_2, u_1, u_0). The additional bit u_3 (see figure 10) determines which one of the two Cartesian products of 2-dimensional cosets in the 4-dimensional coset is chosen. The relationship is shown in table 24 . The bits (v_1, v_0) and (w_1, w_0) are computed from (u_3, u_2, u_1, u_0) using the linear equations given in figure 10 .

Table 24 - Relation between 4-dimensional and 2-dimensional cosets

4-D Coset	u_3 u_2 u_1 u_0	v_1 v_0	w_1 w_0	2-D Cosets
C_4^0	0 0 0 0 1 0 0 0	0 0 1 1	0 0 1 1	$C_2^0 \times C_2^0$ $C_2^3 \times C_2^3$
C_4^4	0 1 0 0 1 1 0 0	0 0 1 1	1 1 0 0	$C_2^0 \times C_2^3$ $C_2^3 \times C_2^0$
C_4^2	0 0 1 0 1 0 1 0	1 0 0 1	1 0 0 1	$C_2^2 \times C_2^2$ $C_2^1 \times C_2^1$
C_4^6	0 1 1 0 1 1 1 0	1 0 0 1	0 1 1 0	$C_2^2 \times C_2^1$ $C_2^1 \times C_2^2$
C_4^1	0 0 0 1 1 0 0 1	0 0 1 1	1 0 0 1	$C_2^0 \times C_2^2$ $C_2^3 \times C_2^1$
C_4^5	0 1 0 1 1 1 0 1	0 0 1 1	0 1 1 0	$C_2^0 \times C_2^1$ $C_2^3 \times C_2^2$
C_4^3	0 0 1 1 1 0 1 1	1 0 0 1	0 0 1 1	$C_2^2 \times C_2^0$ $C_2^1 \times C_2^3$
C_4^7	0 1 1 1 1 1 1 1	1 0 0 1	1 1 0 0	$C_2^2 \times C_2^3$ $C_2^1 \times C_2^0$

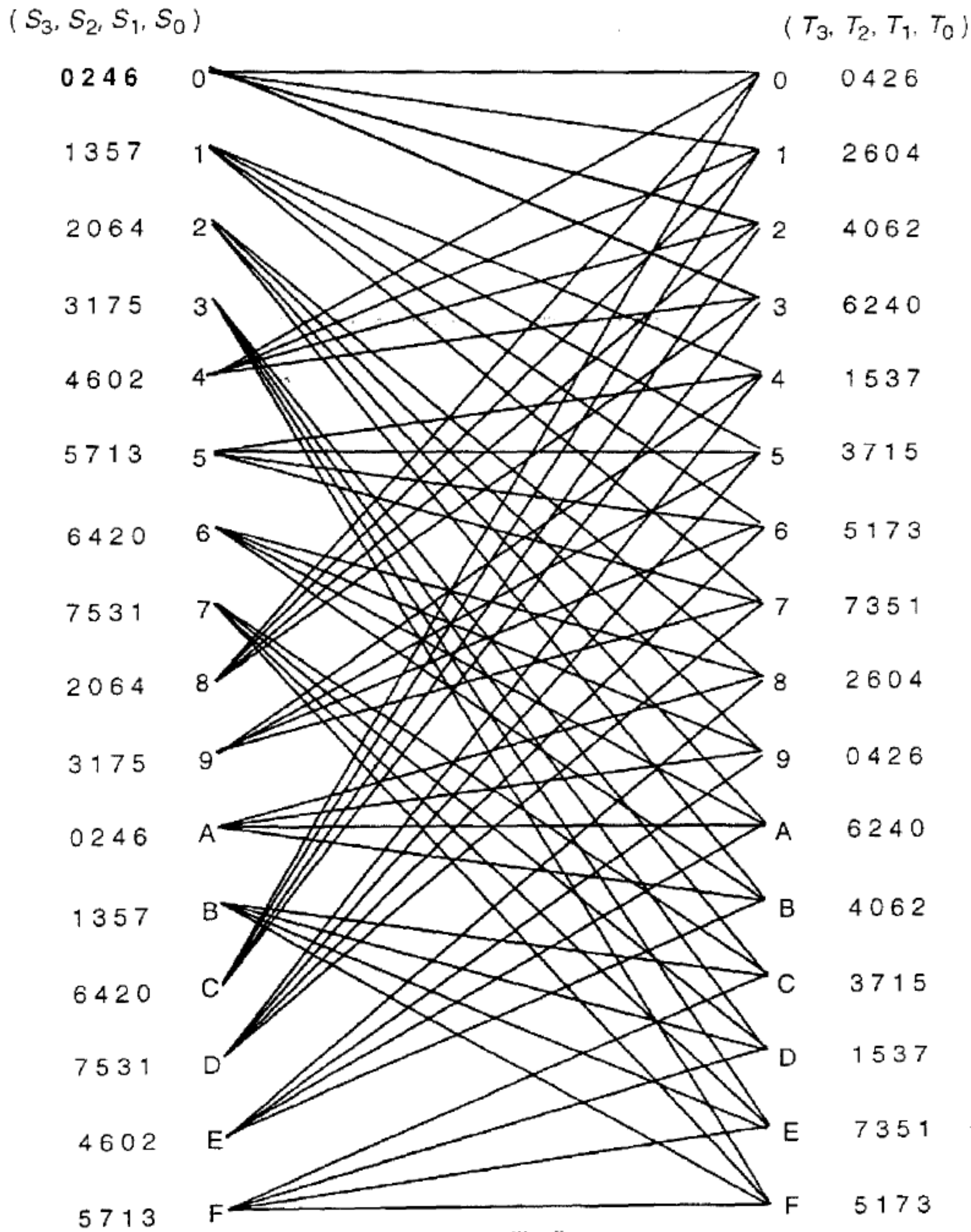


Figure 13 — Trellis diagram

Figure 13 shows the trellis diagram based on the finite state machine in figure 11, and the one-to-one correspondence between (u_2, u_1, u_0) and the 4-dimensional cosets. In the figures, $S = (S_3, S_2, S_1, S_0)$ represents the current state, while $T = (T_3, T_2, T_1, T_0)$ represents the next state in the finite state machine. S is connected to T in the constellation diagram by a branch determined by the values of u_2 and u_1. The branch is labeled with the 4-dimensional coset specified by the values of u_2, u_1 (and $u_0 = S_0$, see figure 11). To make the constellation diagram more readable, the indices of the 4-dimensional coset labels are listed next to the starting and end points of the branches, rather than on the branches themselves. The leftmost label corresponds to the uppermost branch for each state. The constellation diagram is used when decoding the trellis code by the Viterbi algorithm.

6.6.4 Constellation encoder

For a given sub-channel, the encoder shall select an odd-integer point (X, Y) from the square-grid constellation based on the b bits $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$. For convenience of description, these b bits are identified with an integer label whose binary representation is $(v_{b-1}, v_{b-2}, ..., v_1, v_0)$. For example, for b=2, the four constellation points are labeled 0,1,2,3 corresponding to (v_1, v_0) = (0,0), (0,1), (1,0), (1,1), respectively.

6.6.4.1 Even values of b

For even values of b, the integer values X and Y of the constellation point (X, Y) shall be determined from the b bits $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$ as follows. X and Y are the odd integers with twos-complement binary representations $(v_{b-1}, v_{b-3}, ..., v_1, 1)$ and $(v_{b-2}, v_{b-4}, ..., v_0, 1)$, respectively. The most significant bits (MSBs), v_{b-1} and v_{b-2}, are the sign bits for X and Y, respectively. Figure 14 shows example constellations for b = 2 and b= 4.

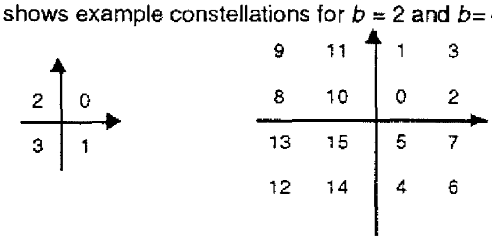


Figure 14 — Constellation labels for b = 2 and b = 4

The 4-bit constellation can be obtained from the 2-bit constellation by replacing each label n by the 2 × 2 block of labels:

$$\begin{matrix} 4n+1 & 4n+3 \\ 4n & 4n+2 \end{matrix}$$

The same procedure can be used to construct the larger even-bit constellations recursively.

The constellations obtained for even values of b are square in shape. The least significant bits $\{v_1, v_0\}$ represent the coset labeling of the constituent 2-dimensional cosets used in the 4-dimensional Wei trellis code.

6.6.4.2 Odd values of b, $b = 3$

Figure 15 shows the constellation for the case b = 3.

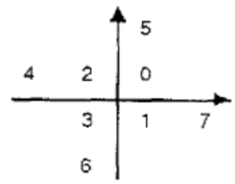


Figure 15 — Constellation labels for $b = 3$

6.6.4.3 Odd values of b, $b>3$

If b is odd and greater than 3, the 2 MSBs of X and the 2 MSBs of Y are determined by the 5 MSBs of the b bits. Let $c = (b+1)/2$, then X and Y have the twos-complement binary representations $(X_c, X_{c-1}, v_{b-4}, v_{b-6}, \ldots, v_3, v_1, 1)$ and $(Y_c, Y_{c-1}, v_{b-5}, v_{b-7}, v_{b-9}, \ldots, v_2, v_0, 1)$, where X_c and Y_c are the sign bits of X and Y respectively. The relationship between X_c, X_{c-1}, Y_c, Y_{c-1} and $v_{b-1}, v_{b-2}, \ldots, v_{b-5}$ is shown in the table 25.

Table 25– Determining the top 2 bits of X and Y

$v_{b-1}, v_{b-2}, \ldots, v_{b-5}$	X_c, X_{c-1}	Y_c, Y_{c-1}
00000	00	00
00001	00	00
00010	00	00
00011	00	00
00100	00	11
00101	00	11
00110	00	11
00111	00	11
01000	11	00
01001	11	00
01010	11	00
01011	11	00
01100	11	11
01101	11	11
01110	11	11
01111	11	11
10000	01	00
10001	01	00
10010	10	00
10011	10	00
10100	00	01
10101	00	10
10110	00	01
10111	00	10
11000	11	01
11001	11	10
11010	11	01
11011	11	10
11100	01	11
11101	01	11
11110	10	11
11111	10	11

Figure 16 shows the constellation for the case b = 5.

	24	26	20	22	
19	09	11	01	03	17
18	08	10	00	02	16
31	13	15	05	07	29
30	12	14	04	06	28
	25	27	21	23	

Figure 16 – Constellation labels for $b = 5$

The 7-bit constellation shall be be obtained from the 5-bit constellation by replacing each label n by the 2 × 2 block of labels:

$4n+1$	$4n+3$
$4n$	$4n+2$

The same procedure shall then be used to construct the larger odd-bit constellations recursively. Note also that the least significant bits $\{v_1, v_0\}$ represent the coset labeling of the constituent 2-dimensional cosets used in the 4-dimensional Wei trellis code.

6.7 Constellation encoder – without trellis coding

An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to $N_{downmax}$ (≤ 15). The constellation encoder shall not use trellis coding with this option.

6.7.1 Bit extraction

Data bytes from the DMT symbol buffer shall be extracted according to a re-ordered bit allocation table b'_i, least significant bit first. The number of bits per tone, b'_i, can take any non-negative integer values not exceeding $N_{downmax}$, with the exception of $b'_i = 1$. For a given tone $b'_i = b$ bits are extracted from the DMT symbol buffer, and these bits form a binary word $\{v_{b-1}, v_{b-2}, ..., v_1, v_0\}$.

6.7.2 Constellation encoder

The constellation encoder shall be as specified in 6.6.4.

6.8 Gain scaling

A gain adjuster, g_i, is used to effect a frequency-variable transmit power spectral density (PSD). It may have two factors:

– a gross gain adjustment of either 1.414 or 2.0 (i.e., 3 or 6 dB), which may be required for sub-carriers # 51 and above (see 12.9.8);
– a fine gain adjustment with a range of approximately 0.8 to 1.2 (i.e., 0 ±1.5 dB), which may be used to equalize the expected error rates for all the sub-channels.

Each point, (X_i, Y_i), or complex number, $Z_i = X_i + jY_i$, output from the encoder is multiplied by g_i:

$Z_i' = g_i Z_i$

NOTE- The g_i define a scaling of the root mean square (rms) sub-carrier levels relative to those used in C-MEDLEY (see 12.6.6). They are independent of any methods that manufacturers may use to simplify implementation (e.g., constellation nesting).

6.9 Modulation

6.9.1 Sub-carriers

The frequency spacing, Δf, between sub-carriers shall be 4.3125 kHz, with a tolerance of $\pm$ 50 ppm.

6.9.1.1 Data sub-carriers

The channel analysis signal defined in 12.6.6 allows for a maximum of 255 carriers (at frequencies $n\Delta f$, $n = 1$ to 255) to be used. If echo cancelling (EC) is used to separate downstream and upstream signals, then the lower limit on n is determined by the ADSL/POTS splitting filters; if frequency division multiplexing (FDM) is used the lower limit is set by the down-up splitting filters. The cut-off frequencies of these filters are completely at the discretion of the manufacturer because, in either case, the range of usable n is determined during the channel estimation.

6.9.1.2 Pilot

Carrier #64 (f = 276 kHz) shall be reserved for a pilot; that is $b_{64} = 0$ and $g_{64} = 1$. The data modulated onto the pilot sub-carrier shall be a constant {0,0}. Use of this pilot allows resolution of sample timing in a receiver modulo-8 samples. Therefore a gross timing error that is an integer multiple of 8 samples could still persist after a micro-interruption (e.g., a temporary short- circuit, open circuit or severe line hit); correction of such timing errors is made possible by the use of the synchronization symbol defined in 6.9.3 .

6.9.1.3 Nyquist frequency

The carrier at the Nyquist frequency (#256) shall not be used for data; other possible uses are for further study.

6.9.2 Modulation by the inverse discrete Fourier transform (IDFT)

The modulating transform defines the relationship between the 512 real values x_k and the Z_i'

$$x_k = \sum_{i=0}^{511} \exp\left(\frac{j\pi ki}{256}\right) Z_i' \quad \text{for } k = 0 \text{ to } 511$$

The encoder and scaler generate only 255 complex values of Z_i' (plus zero at dc, and one real value if the Nyquist frequency is used). In order to generate real values of x_k these values shall be augmented so that the vector Z has Hermitian symmetry. That is,

$Z_i' = \text{conj}\,(Z_{512-i}')$ for i = 257 to 511

6.9.3 Synchronization symbol

The synchronization symbol permits recovery of the frame boundary after micro-interruptions that might otherwise force retraining.

The symbol rate, f_{symb} = 4 kHz, the carrier separation, Δf = 4.3125 kHz, and the IDFT size, N = 512, are such that a cyclic prefix of 40 samples could be used. That is,

$$(512 + 40) \times 4.0 = 512 \times 4.3125 = 2208$$

The cyclic prefix shall, however, be shortened to 32 samples, and a synchronization symbol (with a nominal length of 544 samples) inserted after every 68 data symbols. That is,

$$(512 + 32) \times 69 = (512 + 40) \times 68$$

The data pattern used in the synchronization symbol shall be the pseudo-random sequence PRD, (d_n, for n = 1 to 512) defined by

$$d_n = 1 \qquad \text{for } n = 1 \text{ to } 9$$
$$d_n = d_{n-4} \approx d_{n-9} \qquad \text{for } n = 10 \text{ to } 512$$

The first pair of bits (d_1 and d_2) shall be used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); the first and second bits of subsequent pairs are then used to define the X_i and Y_i, for i = 1 to 255 as follows:

d_{2i+1}, d_{2i+2}		X_i	Y_i
0	0	+	+
0	1	+	–
1	0	–	+
1	1	–	–

NOTES

1 The period of the PRD is only 511 bits, so $d_{512} = d_1$

2 The d_1 - d_9 are re-initialized for each symbol, so each symbol of C-REVERB1 uses the same data

Bits 129 and 130, which modulate the pilot carrier (i = 64), shall be overwritten by {0,0}: generating the {+,+} constellation.

The minimum set of sub-carriers to be used is the set used for data transmission (i.e., those for which $b_i > 0$); sub-carriers for which $b_i = 0$ may be used at a reduced PSD as defined in 6.13.4. The data modulated onto each sub-carrier shall be as defined above; it shall not depend on which sub-carriers are used.

6.10 Cyclic prefix

The last 32 samples of the output of the IDFT (x_k for k = 480 to 511) shall be prepended to the block of 512 samples and read out to the digital-to-analog converter (DAC) in sequence. That is, the subscripts, k, of the DAC samples in sequence are 480.....511,0........511.

The cyclic prefix shall be used for data and synchronization symbols beginning with the R-RATES1 segment of the initialization sequence, as defined in 12.7.4.

6.11 Transmitter dynamic range

The transmitter includes all analog transmitter functions: the D/A converter, the anti-aliasing filter, the hybrid circuitry, and the POTS splitter. The transmitted signal shall conform to the frequency requirements as described in 6.9.1 for frequency spacing.

6.11.1 Maximum clipping rate

The maximum output signal of the transmitter shall be such that the probability of the signal being clipped is no greater than 10^{-7}.

6.11.2 Noise/Distortion floor

The Signal to Noise plus Distortion (SINAD) ratio of the transmitted signal in a given sub-carrier is defined as the ratio of the rms value of the full-amplitude tone in that sub-carrier to the rms sum of all the non-tone signals in the 4.3125 kHz frequency band centered on the sub-carrier frequency. The SINAD is characterized for each sub-carrier used for transmission: $SINAD_i$ represents the signal to noise plus distortion available on the transmitted signal in the ith sub-carrier.

Over the transmission frequency band, the SINAD of the transmitter in any sub-carrier shall be no less than ($3N_{downi}$ + 20) dB, where N_{downi} is defined as the size of the constellation (in bits) to be used on sub-carrier i. The minimum transmitter SINAD shall be at least 38dB (corresponding to an N_{downi} of 6) for any sub-carrier.

6.12 Transmitter spectral response

Figure 17 shows a representative spectral response mask for the transmitted signal. The pass band is defined as the frequency range over which the modem transmits. The low frequency stop band is defined as the POTS band; the high frequency stop band is defined as frequencies greater than 2.208Mhz.

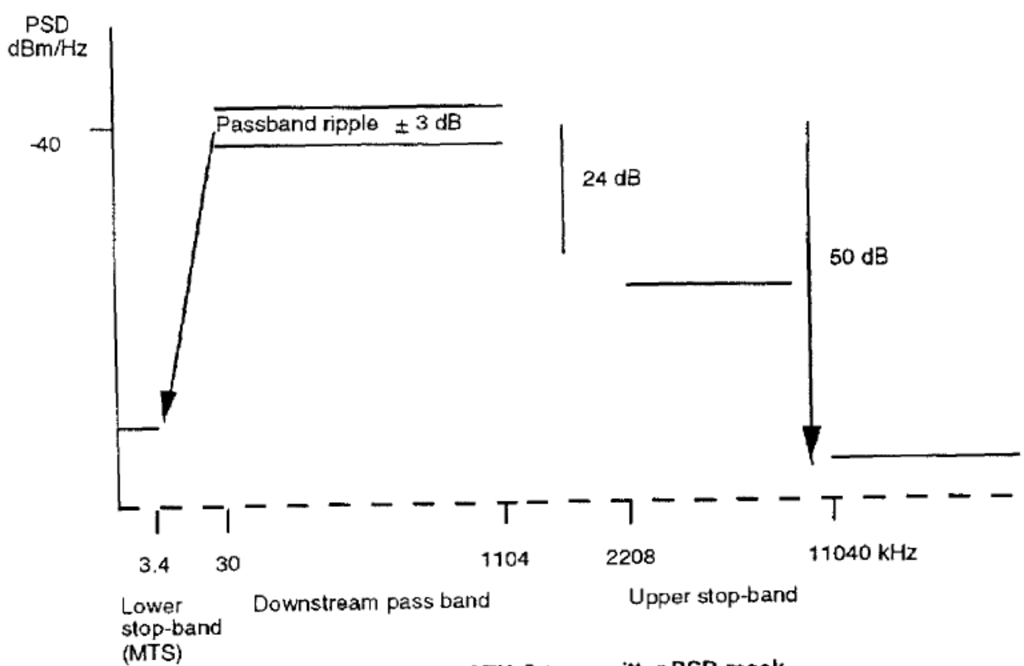


Figure 17 – ATU-C transmitter PSD mask

6.12.1 Pass band response

The pass band ripple shall be no greater than 3 dB, and the group delay variation over the pass band shall not exceed 50 μsec.

6.12.2 Low frequency stop band rejection

The spectral characteristics of the output in the POTS band shall conform to the specifications in 10.7.

6.12.3 High frequency stop band rejection

The PSD in the band above 2.208MHz shall be at least 24 dB below the spectral density of the pass-band mask. (see 12.4.3) . The PSD in the band above 11.04 MHz shall be at least 50dB below the spectral density of the pass-band mask.

6.13 Transmit power spectral density and aggregate power level

There are three different PSD masks for the ATU-C transmit signal, depending on the type of signal sent. In all cases the power in the voice-band that is delivered to the Public Switched Telephone Network (PSTN) interface shall conform to the specification given in 10.7

6.13.1 All initialization signals (except C-ECT) starting with C-REVERB1

The PSD in the band from 25 to 1100 kHz, shall not exceed –40 dBm/Hz for a total power of not greater than 20 dBm. The power in the voice band delivered to the PSTN interface shall conform to the requirements of 10.7. If measurement of the upstream power indicates that power cut-back is necessary, then the PSD should be set at –42, –44, –46, –48, –50, or –52 dBm/Hz (see 12.4.3).

6.13.2 C-ECT

Because C-ECT is a vendor defined signal (see 12.4.5), the PSD specification shall be interpreted only as a maximum. This maximum level is –40 dBm/Hz for the band from 18 to 1100 kHz. Sub-carriers 1 – 5 may be used, but the power in the voice-band that is delivered to the PSTN interface shall conform to the specification given in 10.7.

6.13.3 Steady-state data signal

The PSD in the band from 25 to 1100 kHz shall normally (i.e., without power cut-back or power boost) be –40 dBm/Hz with a maximum of –37 dBm/Hz; levels lower than –40 dBm/Hz on some carriers are discretionary. The normal aggregate power level shall not exceed (–4 +10 log(*ncdown*)) dBm, where *ncdown* is the number of sub-carriers used (20.4 dBm if all sub-carriers are used). The PSD and aggregate power may, however, be changed in any of the following circumstances:

(a) Power cut-back: in this case the PSD and the aggregate power level will be reduced by n multiples of 2 dB (n = 0 to 5) so that they are as follows
- PSDmax = –37 – 2 n dBm/Hz
- Total power = –4 – 2 n + 10log(*ncdown*) dBm

(b) the bits and gains table (see R-B&G in 12.9.8) from ATU-R during initialization may eliminate some of the sub-carriers, and finely adjust (i.e., within ± 3 dB range) the level of others in order to equalize expected error rates on each of the sub-channels;

(c) a power boost: the PSD and aggregate power shall not exceed the following

- PSDmax = –37 dBm/Hz for $0 < i \leq 50$; that is, frequency below 220 kHz
  –31 dBm/Hz for $51 \leq i < 256$; that is frequency above 220 kHz.
- Total power = the sum of the powers (–4 + 10 log(*ncdown1*)) and (2 + 10log(*ncdown2*)),

where *ncdown1* and *ncdown2* arethe number of sub-carriers used in the sub-bands i = 0 to 50, and i = 51 to 255, respectively

These specifications are shown in figure 18, where the possible power cut-back in multiples of 2 dBm and power boost of 6 dBm above 220 kHz are illustrated .

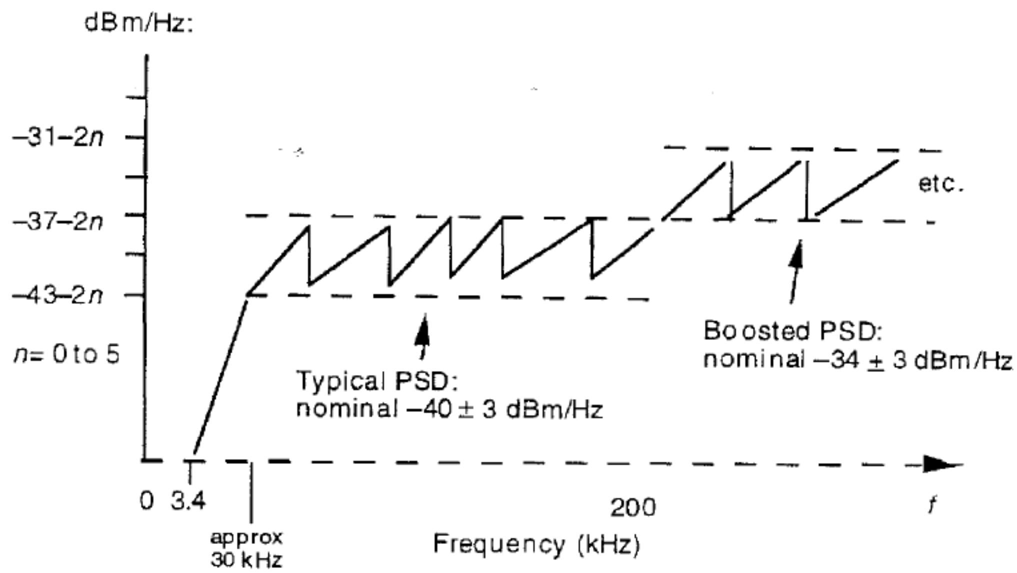


Figure 18 – ATU-C transmitter PSD mask: pass-band detail

6.13.4 Synchronization symbol

The PSD of those sub-carriers for which $b_i > 0$ or $b_i = 0$ and $g_i > 0$ shall be the same as for the initialization signal C-REVERB1; that is, nominally –40 dBm/Hz. The PSD for those sub-carriers for which $b_i = 0$ and $g_i = 0$ shall be no higher than –48 dBm/Hz.

The PSD of a synchroniazation symbol thus differs from that of the data signals surrounding it by the g_i, which are applied only to the data carriers. These g_i were calculated for the multipoint constellations in order to equalize the expected error rate on all sub-channels, and are therefore irrelevant for most of the 4QAM signals of the synchronization symbol.

7 ATU-R functional characteristics

7.1 ATU-R input and output data interfaces

The functional data interfaces at the ATU-R are shown in figure 19 . Output interfaces for the high-speed downstream simplex bearer channels are designated AS0 through AS3; input–output interfaces for the duplex bearer channels are designated LS0 through LS2. There may also be a functional interface to transport maintenance indicators from the SMs (service modules) to the ATU-R; this interface may physically be combined with the LS0 upstream interface.

The data rates of the input and output data interfaces at the ATU-R for the default configurations are specified in this clause.

The total net bearer capacity that can be transmitted in the upstream direction depends on the loop characteristics. The rate of the duplex bearer at the LS0 interface and the availability of the LS1 and LS2 options correspond to the transport class as discussed in 5.3, for the default configurations.

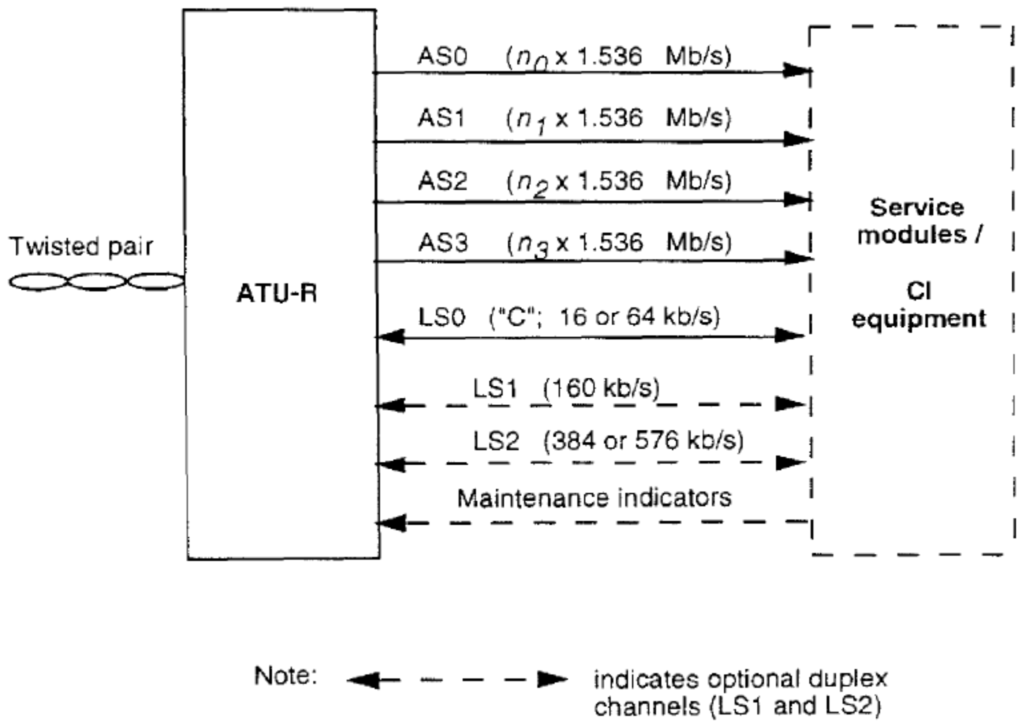


Figure 19 – ATU-R data interfaces

7.1.1 Downstream simplex channels – Transceiver bit rates

The simplex channels are transported in the downstream direction only; therefore their data interfaces at the ATU-R operate only as outputs. The rates are the same as those for the ATU-C transmitter, as specified in 6.1.1.

7.1.2 Duplex channels – Transceiver bit rates

The duplex channels are transported in both directions, so the ATU-R shall provide both input and output data interfaces. The rates are the same as for the ATU-C, as specified in 6.1.2.

7.2 Framing

Framing of the upstream signal (ATU-R transmitter) is specified in this subclause; it closely follows the downstream framing (ATU-C transmitter), which is specified in 6.2, but with the following exceptions:

- there are no ASX channels or an AEX byte;
- a maximum of three channels exist, so that only three B_F, B_I pairs are specified;
- the default FEC coding parameters and interleave depth differ (see table 26);
- four bits of the "fast" and "synch" bytes are unused (corresponding to the bit positions used by the ATU-C transmitter to specify synchronization control for the ASX channels) (see tables 27 and 28).
- if the LS2 frame integrity option is installed, condition (d) in 6.2.4 does not apply for the insertion of an LS2 frame verification pointer.

7.2.1 Data symbols

The ATU-R transmitter is functionally similar to the ATU-C transmitter, as specified in 6.2.1, with the exception that up to three duplex data channels are synchronized to the 4 kHz ADSL DMT symbol rate (instead of up to four simplex and three duplex channels as is the case for the ATU-C) and multiplexed into the two separate buffers (fast and interleaved). The ATU-R transmitter and its associated reference points for data framing are identical to the structure shown in figure 2, with the exception that the AS0..AS3 channels do not appear at the input of the Mux/Synch Control.

7.2.1.1 Superframe structure

The superframe structure of the ATU-R transmitter shall be identical to that of the ATU-C transmitter, as specified in 6.2.1.1.

7.2.1.2 Frame structure

Each frame of data shall be encoded into a multicarrier symbol, as described in 7.3 through 7.6. As specified for the ATU-C and shown in figure 2, each frame is composed of a fast data buffer and an interleaved data buffer, and the frame structure has a different appearance at each of the reference points (A, B, and C). The bytes of the fast buffer shall be clocked into the constellation encoder first, followed by the bytes of the interleaved data buffer. Bytes are clocked least significant bit first.

The assignment of user data streams to the fast and interleaved buffers shall be configured during initialization (see 12.6) with the exchange of a (B_F, B_I) pair for each data stream, where B_F designates the number of bytes of a given data stream to allocate to the fast buffer, and B_I designates the number of bytes allocated to the interleaved data buffer.

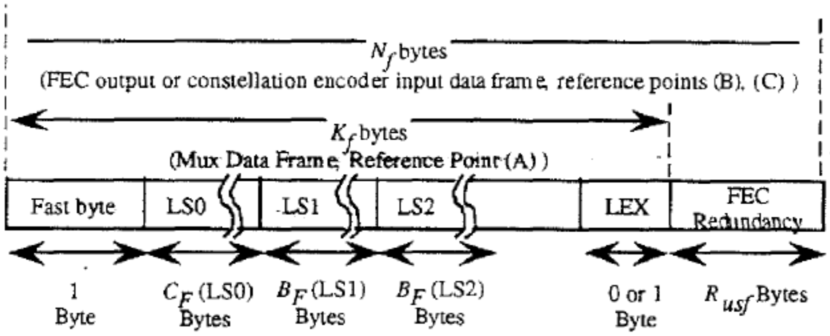
The three possible (B_F, B_I) pairs are B_F(LSX), B_I(LSX) for X = 0, 1 and 2, for the duplex channels; they are specified as for the ATU-C in 6.2.1.2.

The three values of the (B_F, B_I) pairs for the default configurations shall be as specified for the ATU-C in table 16.

7.2.1.2.1 Fast data buffer

The frame structure of the fast data buffer is shown in figure 20 for the three reference points that are defined in figure 2 . This structure is the same as that specified for the ATU-C with the following exceptions:

- ASX bytes do not appear;
- the AEX byte does not appear;
- R_{usf} FEC redundancy bytes are used (as contrasted with R_{dsf}).



$$K_f = 1 + \sum_{j=0}^{2} B_F(LS_j) + L_F,$$

$$C_F(LS0) = \begin{cases} 0, & B_F(LS0) = 255, \\ B_F(LS0) & \text{otherwise.} \end{cases}$$

where $L_F = \begin{cases} 0, & \sum_{j=0}^{2} B_F(LS_j) = 0, \\ 1 & \text{otherwise.} \end{cases}$

$$N_f = K_f + R_{usf},$$

where R_{usf} = # FEC Redundancy Bytes.

NOTE – $L_F = 1$ when $B_F(LS0) = 255$

Figure 20 – Fast data buffer – ATU-R transmitter

At reference point A in figure 2, the mux data frame, the fast buffer always contains at least the "fast" byte. This is followed by B_F(LS0) bytes of channel LS0, then B_F(LS1) bytes of channel LS1, and B_F(LS2) bytes of channel LS2, and if any B_F(LSX) is non-zero, an LEX byte.

When B_F(LS0) = 255 (Binary 11111111), no separate bytes are included for the LS0 channel. Instead, the 16 kbit/s C channel is transported in every other LEX byte on average, using the synch byte to denote when to add the LEX byte to the LS0 data stream.

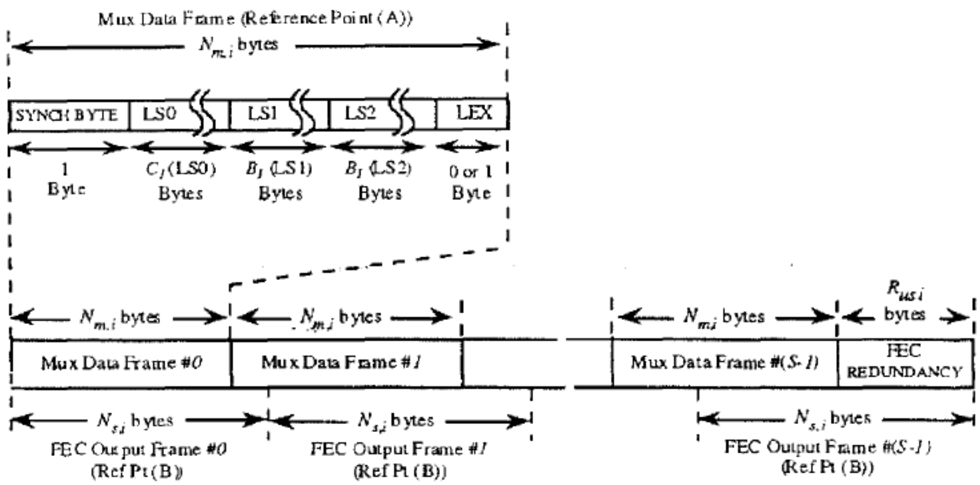
R_{usf} FEC redundancy bytes are added to the mux data frame (reference point A) to produce the FEC output data frame (reference point B), where R_{usf} is given in the C-RATES1 signal options received from the ATU-C during initialization (see clause 12). R_{usf} is equal to 4 for the default configurations specified in 6.2.1.2. When no data streams are allocated to the fast buffer, R_{usf} = 0 (no FEC redundancy bytes are added). Because the data from the fast buffer is not interleaved, the constellation encoder input data frame (reference point C) is identical to the FEC output data frame (reference point B).

7.2.1.2.2 Interleaved data buffer

The frame structure of the interleaved data buffer is shown in figure 21 for the three reference points that are defined in figure 2. This structure is the same as that specified for the ATU-C, with the following exceptions:

- ASX bytes do not appear;

- the AEX byte does not appear;
- R_{usi} FEC redundancy bytes are used (contrasted with R_{dsi}).



$N_{m,i} = 1 + \sum_{j=0}^{2} B_I(LS_j) + L_I$,

where $L_I = \begin{cases} 0, & \sum_{j=0} B_I(LS_j) = 0, \\ 1 & \text{otherwise.} \end{cases}$

(Note: $L_I = 1$ when $B_I(LS0) = 255$)

$C_I(LS0) = \begin{cases} 0, & B_I(LS0) = 255 \text{ (Binary 11111111)}, \\ B_I(LS0) & \text{otherwise.} \end{cases}$

$N_{s,i} = (S * N_{m,i} + R_{usi}) / S$,

where R_{usi} = # FEC Redundancy Bytes,
and S = # DMT symbols per FEC codeword.

Figure 21 – Interleaved data buffer – ATU-R transmitter

The FEC coding overhead, the number of symbols per FEC codeword, and the interleave depth are given in the C-RATES1 options received from the ATU-C during initialization (see clause 12). For the default configurations specified in 6.2.1.2, the coding parameters are given in table 26 .

Table 26 - Default FEC coding parameters and interleave depth– ATU-R transmitter

	R_{usi} (FEC redundancy bytes)	S (symbols per codeword)	Interleave depth (FEC codewords)
Transport classes 1, 2M-1	16	8	8
Transport classes 2, 3, 2M-2	16	16	4
Transport classes 4, 2M-3	16	16	4
Synch byte only	4	4	16

7.2.1.3 Cyclic redundancy check (crc)

Two cyclic redundancy checks (crc's) – one for the fast data buffer and one for the interleaved data buffer – are generated for each superframe and transmitted in the first frame of the following superframe. Eight bits per buffer type (fast or interleaved) per superframe are allocated to the crc check bits. These bits are computed from the k message bits using the equation:

The crc bits are transported in the "fast byte" (8 bits) of frame 0 in the fast data buffer, and the "synch byte" (8 bits) of frame 0 in the interleaved data buffer.

The bits covered by the crc include;

- for the fast data buffer:
  - *frame 0:* LSX bytes ($X = 0, 1, 2$), followed by the LEX byte;
  - *all other frames:* "fast" byte, followed by LSX bytes ($X = 0, 1, 2$), and LEX byte.

- for the interleaved data buffer:
  - *frame 0:* LSX bytes ($X = 0, 1, 2$), followed by the LEX byte;
  - *all other frames:* "synch" byte, followed by LSX bytes ($X = 0, 1, 2$), and LEX byte.

Each byte shall be clocked into the crc least significant bit first.

The crc-generating polynomial, and the method of generating the crc byte are the same as for the downstream data; these are specified in 6.2.1.3.

7.2.2 Synchronization

The input data streams shall be synchronized to the ADSL clock using the synchronization control byte and the LEX byte. Forward-error-correction coding is always applied to the synchronization control byte(s).

7.2.2.1 Synchronization for the fast data buffer

Synchronization control for the fast data buffer can occur in frames 2 through 33 and 36 through 67 of an ADSL superframe as described in 7.2.1.1, where the "fast" byte may be used as the synchronization control byte.

The format of the "fast" byte when used as synchronization control for the fast data buffer shall be as given in table 27.

In the case where no signals are allocated to the interleaved data buffer, the "synch" byte shall carry the aoc data directly as shown in figure 7.

Table 27 – Fast byte format for synchronization – Fast data buffer

Bit	Application	Specific usage
sc7-sc4	not used	set to "0" until specified otherwise
sc3, sc2	LSX channel designator	"00" : channel LS0 "01" : channel LS1 "10" : channel LS2 "11" : do nothing to any LSX channel
sc1	Synchronization control for the designated LSX channel	"1" : add LEX byte to designated LSX channel "0" : delete last byte from designated LSX channel
sc0	Synch/eoc designator	"0" : perform synchronization control as indicated in sc7-sc1 "1" : this byte of current (even-numbered) frame and of frame that immediately follows is an eoc frame

No synchronization action shall be taken for those frames in which the "fast" byte is used for crc, fixed indicator bits, or eoc.

When the data rate of the C channel is 16 kbit/s, the LS0 sub-channel shall be transported in the LEX byte, using the "add LEX byte to designated LSX channel", with LS0 as the designated channel, every other frame on average.

7.2.2.2 Synchronization for the interleaved data buffer

Synchronization control for the interleaved data buffer can occur in frames 1 through 67 of an ADSL superframe as described in 7.2.1.1, where the "synch" byte may be used as the synchronization control byte.

The format of the "synch" byte when used as synchronization control for the interleaved data buffer is given in table 28.

Table 28 - Synch byte format for synchronization – Interleaved data buffer

Bit	Application	Specific usage
sc7-sc4	not used	set to "0" until specified otherwise
sc3, sc2	LSX channel designator	"00" : channel LS0 "01" : channel LS1 "10" : channel LS2 "11" : do nothing to any LSX channel
sc1	Synchronization control for the designated LSX channel	"1" : add LEX byte to designated LSX channel "0" : delete last byte from designated LSX channel
sc0	Synch/aoc designator	"0" : perform synchronization control as indicated in sc3-sc1 "1" : LEX byte carries ADSL overhead control channel data; a delete synchronization control may be allowed as indicated in sc3-sc1

No synchronization action shall be taken during frame 0, where the "synch" byte is used for crc, and the LEX byte carries aoc.

When the data rate of the C channel is 16 kbit/s, the LS0 sub-channel shall be transported in the LEX byte, using the "add LEX byte to designated LSX channel", with LS0 as the designated channel, every other frame on average.

7.3 Scramblers

The binary data streams output from the fast and interleaved buffers shall be scrambled separately using the same algorithm as for the downstream signal, specified in 6.3

7.4 Forward error correction

The upstream data are Reed-Solomon coded and interleaved using the same algorithm as for the downstream data, specified in 6.4

7.5 Tone ordering

The tone ordering algorithm shall be the same as for the downstream data, specified in 6.5

7.6 Constellation encoder - with trellis coding

Block processing of Wei's 16-state 4-dimensional trellis code to improve system performance is optional . If it is implemented, an algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to N_{upmax}, where $N_{upmax} \leq 15$.

The encoding algorithm is the same as that used for downstream data (with the substitution of the constellation limit of N_{upmax} for $N_{downmax}$), specified in 6.6

7.7 Constellation encoder – without trellis coding

An algorithmic constellation encoder shall be used to construct constellations with a maximum number of bits equal to N_{upmax} , where $15 \geq N_{upmax} \geq 8$. The encoding algorithm is the same as that used for downstream data (with the substitution of the constellation limit of N_{upmax} for

$N_{downmax}$), which is specified in 6.7. The constellation encoder does not use trellis coding with this option.

7.8 Gain scaling

Each point (X_i, Y_i) or complex number, $Z_i = X_i + jY_i$, output from the encoder is multiplied by the fine gain adjuster, g_i:

$$Z_i' = g_i Z_i$$

The g_i define a scaling of the rms sub-carrier levels relative to those used in R-MEDLEY (see 12.7.8). They are independent of any methods that manufacturers may use to simplify implementation (e.g., constellation nesting).

7.9 Modulation

The frequency spacing, Δf, between sub-carriers shall be 4.3125 kHz with a tolerance of $\pm$ 50 ppm.

7.9.1 Sub-carriers

7.9.1.1 Data sub-carriers

The channel analysis signal, defined in 11.5.2, allows for a maximum of 31 carriers (at frequencies $n\Delta f$, n=1 to 31) to be used. The lower limit on n is determined by the ADSL-POTS splitting filters; if FDM is used to separate the upstream and downstream signals, the upper limit on n is set by the down-up splitting filters. The cut-off frequencies of these filters are completely at the discretion of the manufacturer because in either case the range of usable n is determined during the channel estimation.

7.9.1.2 Pilot

Carrier #16 (f = 69.0 kHz) shall be reserved for a pilot; that is $b_{16} = 0$ and $g_{16} = 1$. The data modulated onto the pilot sub-carrier shall be a constant {0,0}. Use of this pilot allows resolution in a receiver of sample timing modulo-8 samples. Therefore a gross timing error that is an integer multiple of 8 samples, could still persist after a micro-interruption (e.g., a temporary short- circuit, open circuit or severe line hit); correction of these is made possible by the use of the synchronization symbol defined in 7.7.4.

7.9.1.3 Nyquist frequency

The carrier at the Nyquist frequency (#32) shall not be used for data; other possible uses are for further study.

7.9.2 Modulation by the inverse discrete fourier transform

The modulating transform defines the relationship between the 64 real values x_k and the Z_i'

$$x_k = \sum_{i=0}^{63} \exp(j\pi\, ki/32)\, Z_i'$$

The encoder and scaler generate only 31 complex values of Z_i' (plus zero at dc and one real value if the Nyquist frequency is used). In order to generate real values of x_k these values shall be augmented so that the vector Z has Hermitian symmetry. That is,

$$Z_i' = \text{conj}\,[Z_{64-i}'] \qquad \text{for } i = 33 \text{ to } 63$$

7.9.3 Synchronization symbol

The synchronization symbol permits recovery of the frame boundary after micro-interruptions that might otherwise force retraining.

The symbol rate, f_{symb} = 4 kHz, the sub-carrier separation, Δf = 4.3125 kHz, and the IDFT size, N = 64, are such that a cyclic prefix of 5 samples could be used. That is,

$$(64 + 5) \times 4.0 = 64 \times 4.3125 = 276$$

The cyclic prefix, however, is shortened to 4 samples, and a synchronization symbol (with a nominal length of 68 samples) is inserted after every 68 data symbols. That is,

$$(64 + 4) \times 69 = (64 + 5) \times 68$$

The data pattern used in the synchronization symbol is the pseudo-random sequence PRU (d_n, for n = 1 to 64), defined by

$$d_n = 1 \quad \text{for } n = 1 \text{ to } 6$$
$$d_n = d_{n-5} \approx d_{n-6} \quad \text{for } n = 7 \text{ to } 64$$

The bits shall be used as follows: the first pair of bits (d_1 and d_2) is used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); then the first and second bits of subsequent pairs are used to define the X_i and Y_i for i = 1 to 31 as follows:

d_{2i+1}, d_{2i+2}		X_i, Y_i	
0	0	+	+
0	1	+	–
1	0	–	+
1	1	–	–

NOTES

1 The period of PRU is only 63 bits, so $d_{64} = d_1$

2 The $d_1 - d_6$ are re-initialized for each symbol, so each symbol of C-REVERB1 uses the same data

Bits 33 and 34, which modulate the pilot carrier (i=16) are overwritten by {0,0}, generating the {+,+} constellation.

The minimum set of sub-carriers to be used is the set used for data transmission (i.e., those for which b_i> 0); sub-carriers for which b_i = 0 may be used at a reduced PSD as defined in 7.13.4. The data modulated onto each sub-carrier shall be as defined above; it shall not depend on which sub-carriers are used.

7.10 Cyclic prefix

The cyclic prefix shall be used for data and synchronization symbols beginning with segment R-RATES1 of the initialization sequence, as defined in 12.7.2.1

The last 4 samples of the output of the IDFT (x_k for k = 61 to 63) shall be prepended to the block of 64 samples and read out to the DAC in sequence. That is, the subscripts, k, of the DAC samples in sequence are 60...63,0...63.

7.11 Transmitter dynamic range

The transmitter includes all analog transmitter functions: the D/A converter, the anti-aliasing filter, the hybrid circuitry, and the POTS splitter. The transmitted signal shall conform to the frequency requirements described in section 7.9.1 for frequency spacing.

7.11.1 Maximum clipping rate

The maximum output signal of the transmitter shall be such that the probability of the signal being clipped is no greater than 10^{-7}.

7.11.2 Noise/Distortion floor

The Signal to Noise plus Distortion (SINAD) ratio of the transmitted signal in a given sub-carrier is defined as the ratio of the rms value of the full-amplitude tone in that sub-carrier to the rms sum of all the non-tone signals in the 4.3125 kHz frequency band centered on the tone frequency. The SINAD is characterized for each sub-carrier used for transmission: SINADi represents the signal to noise plus distortion available on the transmitted signal in the ith sub-carrier.

Over the transmission frequency band, the SINAD of the transmitter in any sub-carrier (or DMT tone) shall be no less than ($3N_{upi}$ + 20) dB, where N_{upi} is defined as the size of the constellation (in bits) to be used in sub-carrier i. The minimum transmitter SINAD shall be at least 38 dB (corresponding to an N_{upi} of 6) for any sub-carrier.

7.12 Transmitter spectral response

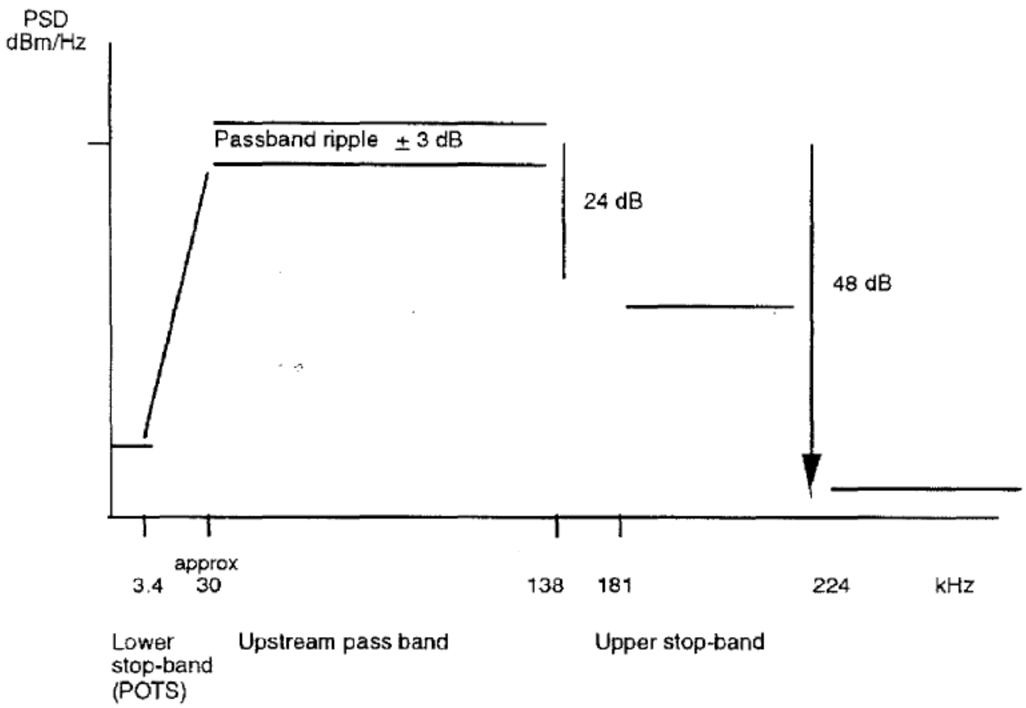


Figure 22 – ATU-R transmitter PSD mask

Figure 22 shows a representative spectral response mask for the transmitted signal. For purposes of this discussion, the pass band is defined as the frequency range over which the modem transmits. The low frequency stop band is defined as the POTS band. The high frequency stop band is defined as frequencies greater than 181 kHz, which is approximately $10\Delta f$ above the maximum pass band frequency (138kHz).

7.12.1 Pass band response

The pass band ripple shall be no greater than ± 3dB, and the group delay variation over the pass band shall not exceed 50µs.

7.12.2 Low frequency stop band rejection

The spectral characteristics of the output in the POTS band shall conform to the specifications in 10.3.

7.12.3 High frequency stop band rejection

The PSD in the band above 181kHz shall be at least 24 dB below the spectral density of the pass-band mask. (see 12.4.3) The PSD in the band above 224 kHz (138kHz+ 86kHz) shall be at least 48dB below the spectral density of the pass-band mask.

7.13 Transmit power spectral density and aggregate power level

There are three different PSD masks for the ATU-R transmit signal, depending on the type of signal sent. In all cases the power in the voice-band that is delivered to the POTS interface shall conform to the specification given in 10.2.

7.13.1 All initialization signals (except R-ECT) starting with R-REVERB1

The PSD in the band from 25 to 138 kHz, shall not exceed –38 dBm/Hz for a total power of not greater than 13 dBm. The power in the voice band delivered to the POTS interface shall conform to the requirements of 10.4.

7.13.2 R-ECT

Because R-ECT is a vendor-defined signal (see 12.5.4), the PSD specification shall be interpreted only as a maximum. This maximum level is –38 dBm/Hz for the band from 18–138 kHz. Sub-carriers 1–4 may be used, but the power in the voice-band that is delivered to the POTS interface shall conform to the specification given in 10.4.

7.13.3 Steady-state data signal

The transmit PSD in the frequency region from 25–138 kHz shall normally be –38 dBm/Hz with a maximum of -35 dBm/Hz; levels lower than –38 dBm/Hz on some sub-carriers are discretionary. The aggregate power level shall not exceed (–2 + 10 log *ncup*) dBm, where *ncup* is the number of sub-carriers used (13 dBm if all sub-carriers are used). The bits and gains table (see C-B&G in 12.8.7), calculated by, and sent from the ATU-C during initialization, may eliminate some of the sub-carriers, and finely adjust (i.e., within a ± 3 dB range) the level of others in order to equalize expected error rates on each of the sub-channels.

7.13.4 Synchronization symbol

The PSD of those sub-carriers for which $b_i > 0$ or $b_i = 0$ and $g_i > 0$ shall be the same as for the initialization signal R-REVERB1; that is, nominally –38 dBm/Hz. The PSD for those sub-carriers for which $b_i = 0$ and $g_i = 0$ shall be no higher than –48 dBm/Hz.

The PSD of a synchroniazation symbol thus differs from that of the data signals surrounding it by the g_i, which are applied only to the data carriers. These g_i are calculated for the multipoint constellations in order to equalize the expected error rate on all sub-channels, and are therefore irrelevant for most of the 4QAM signals of the synchronization symbol.

8. ADSL–POTS splitter functional characteristics

When ADSL is provided with POTS on the same twisted pair an ADSL–POTS splitting function shall be performed at each end of the line.

At the ATU-R the splitting functions are

- combining the POTS and the ATU-R transmit signals towards the U-R;

- separating the POTS and ADSL signals received from the U-R;

- protecting the POTS from voice-band interference from signals generated by both the ATU-R and ATU-C;

- protecting both ATU-R and ATU-C receivers from all POTS-related signals, particularly dial pulses, ringing and ring trip.

Protection of the ADSL receivers from those components of POTS-related signals that fall in the voiceband may be partially performed by the receivers themselves.

These functions shall be performed while meeting all requirements for POTS performance, such as echo and singing return loss, as specified in 10.1. Also these functions shall be performed in such a way that if either ATU is turned off, or if power is lost, continuity through the voice-band path is maintained, and telephone service is not interrupted.

The combination and separation of POTS and ADSL signals is achieved by low-pass and high-pass filtering. The POTS signal occupies the band up to 3.4 kHz; the bands occupied by the ADSL upsteam and downstream signals are vendor options, but leakage of the signals into the voice band shall be constrained as defined in 10.4.

The functional characteristics of the ADSL–POTS splitter at the ATU-C are the same as those at the ATU-R, but the performance requirements may be different because of the different relative levels of signals and interferences.

9 ATU-R to service module (T_{SM}) interface requirements

Two distinctive T-interfaces are defined, see figure 23. The T_A interface preserves the ADSL channelization and the entire payload. The TTL-type signals at the T_A interface with separate clocks for each channel are intended for connection of the ADSL transceiver to other elements that sre located within a few centimeters. The T_B interface is intended to to provide a simple point-to-point connection of the ATU-R to a service module, which may be 50 meters distant (greater distances are for further study). Both interfaces are optional and not necessary for compliance with the standard. An additional composite, single-channel T interface is for further study.

Functionally, the T_A-interface preserves ADSL channelization and the entire payload, and the T_B-interface is designed as a simple point-to-point interface between the ADSL entrance unit and the service module. Future issues of this standard may update this interface or specify a multipoint ATU-R to SM interface. In particular, an additional composite, single channel T-interface is for further study, and the T_A-interface may or may not be included in future issues of the standard.

9.1 T_A-interface definitions

The T_A-interface consists of a DATA and a clock (CLK) line for each of the four simplex ASX channels and for each direction of each of the three duplex LSX channels. The CLKs emanating from the ATU-R will not necessarily be smooth nor synchronous to one another. Any clock smoothing will be performed at the ATU-R to SM interface card.

The routing of proper ASX and LSX channels shall be performed by the ATU-R to SM interface card. An optional C-channel processor is specified for a multiple interface card configuration. The LS0 DATA and CLK from the ATU-R are passed to the C-channel processor before passing to the individual interface cards. The demultiplexing process of the LS0 channel can be performed by either the C-channel processor or by the individual SM's. Inversely, the upstream LS0 DATA and CLK from each interface card are collected and formatted at the C-channel processor, which in turn outputs a single upstream LS0 DATA and CLK to the ATU-R for transmission back to the ATU-C. DATAs and CLKs to and from the C-channel processor will be at standard logic levels, as specified in 9.1.1.

T_A-interface signals and timing are defined as follows:

–ASX Channels:

- *Signal Levels:* Standard TTL logic levels;
- *Data:* NRZ;
- *Clock:* Standard logic levels, 50% (±15%) duty cycle;
- *Clock polarity:* Data changes on rising clock edge;
- *Nominal clock frequency:* 1.536 MHz, 1.544 MHz, 3.072 MHz, 4.608 MHz, or 6.144 MHz, depending on configuration (2.048 MHz optional).

– LSX Channels:

- *Signal levels:* Standard TTL logic levels;
- *Data:* NRZ;
- *Clock:* Standard logic levels, 50% (±15%) duty cycle;
- *Clock polarity:* Data changes on rising clock edge;
- *Nominal clock frequency:* 16 kHz, 64 kHz, 160 kHz, 384 kHz, or 576 kHz, depending on configuration.

9.2 T_B-interface definitions

The T_B-interface allows a point-to-point connection that is at most 50 meters from the ADSL entrance unit to the SM.; greater distances are for further study. The T_B-interface is located at the output of the ATU-R to SM interface card and consists of three separate simplex channels:

- a downstream ASX channel to the SM;
- a downstream LS0 channel to the SM;
- an upstream LS0 channel from the SM.

The optional LS1 (ISDN-BRA) channel and LS2 (H0) channel interfaces may also be provided at the T_B-interface .

T_B-interface signals and timing are defined as follows:

– ASX channel:

- *Wire type:* Transformer-balanced, twisted-pair wire;
- *Coding:* B8ZS;
- *Bit rates:* 1.544, 1.536, 3.072, 4.608, or 6.144 Mbit/s depending on configuration (2.048 Mbit/s optional with G.703 interface);
- *Maximum transmit level:* 3 volts peak.

– LS0 channel:

- *Wire type:* Transformer-balanced, twisted-pair wire;
- *Coding:* Biphase (Manchester);
- *Bit Rates:* 16 or 64 kbit/s depending on configuration;
- *Interface:* EIA RS-422.

– LS1 Channel (optional) interface: ISDN-BRA U or S/T interface.

– LS2 channel (optional) interface: Partially filled T1 with same specifications as the ASX channel above.

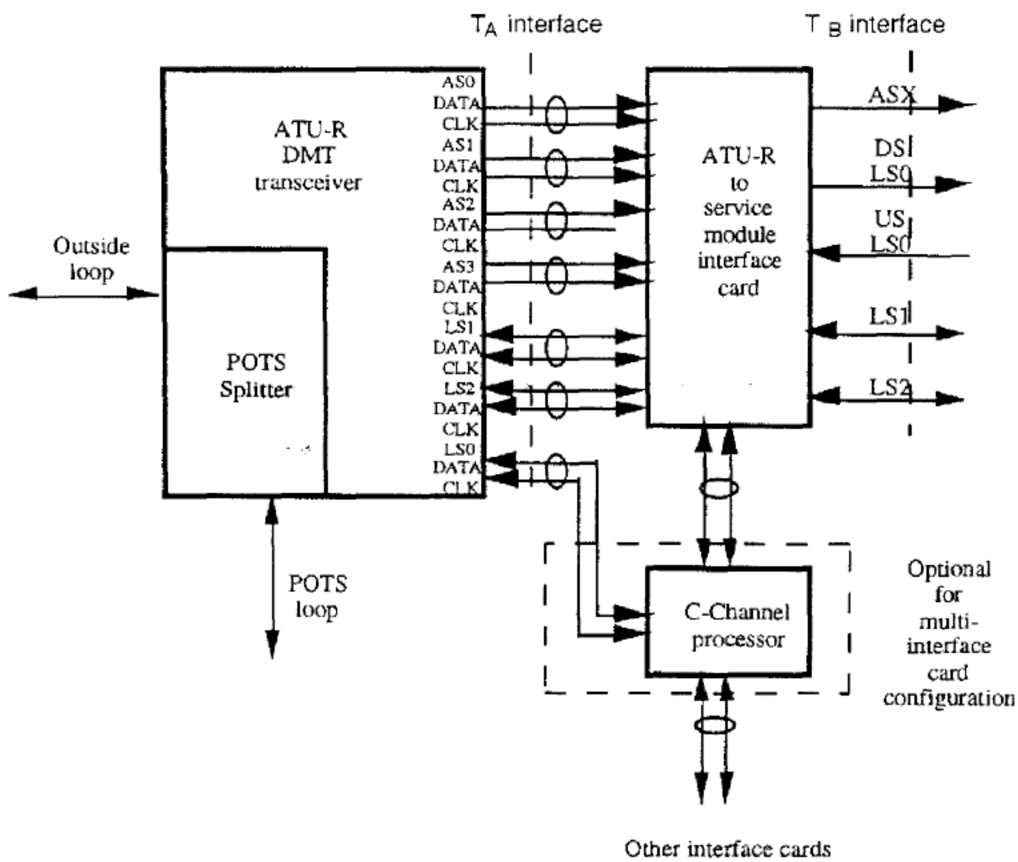


Figure 23 - ADSL entrance unit block diagram

10. Electrical characteristics

10.1 DC characteristics

All requirements of this standard shall be met in the presence of all POTS loop currents from 0 mA to 100 mA. Splitters shall pass POTS tip-to-ring dc voltages of 0 V to 105 V and ringing signals of 40 V to 150 V rms at any frequency from 15.3 Hz to 68 Hz with a dc component in the range from 0 V to 105 V.

The dc resistance from tip-to-ring at the PSTN interface with the U-C interface shorted, or at the POTS interface with the U-R interface shorted, shall be less than or equal to 25 ohms. The dc resistance from tip to ground and from ring to ground at the PSTN interface with the U-C interface open, or at the POTS interface with the U-R interface open shall be greater than or equal to 5 megohms.

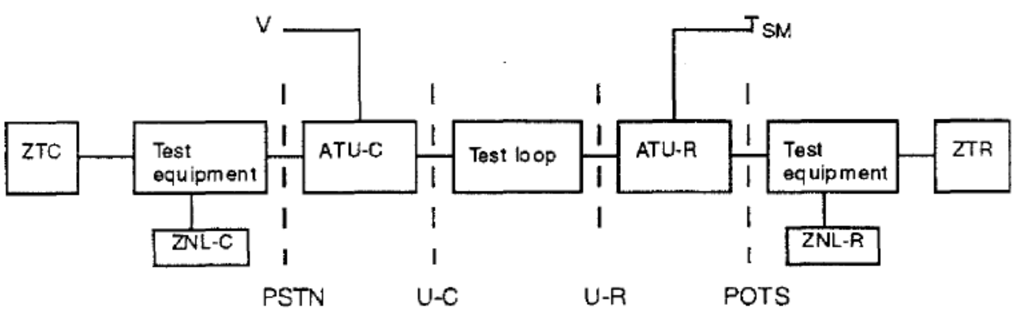
10.2 Voice-band characteristics

10.2.1 Metallic (differential mode)

A common test setup shall be used for measurement of the voice band insertion loss, attenuation distortion, delay distortion, return loss, and noise and distortion. All measurements shall be performed between the PSTN and POTS interfaces of the ATU-C and ATU-R, respectively, with a variety of reference loops between the U-C and U-R reference points. The following loops shall be used:

- a null loop;
- ANSI T1.601-1992 resistance-designed loops 7, 9, and 13;
- Committee T1 TR 28 CSA loops 4, 6, 7, and 8;
- 26 AWG wire pairs of lengths 0.5 kft, 2.0 kft, and 5.0 kft.

Figure 24 defines the test configuration and the value of the test components for all electrical characteristics defined in this section unless otherwise specified; not all equipment will be required for all tests.



Where:

ZTC = 900 ohms in series with 2.16 µF for return loss measurements.
= 900 ohms for loss and noise measurements.
ZTR = 600 ohms.
ZNL-C = 800 ohms in parallel with the series connection of a 100 ohm resistor and a 50 nF capacitor.
ZNL-R =1330 ohms in parallel with the series connection of a 348 ohm resistor and a 100 nF capacitor (provisional values).

Figure 24 – Test setup for transmission and impedance measurements

10.2.1.1 Insertion loss

For each of the test loops specified in 10.1.2, and using the test set-up shown in figure 24, the insertion loss from the PSTN interface to the POTS interface shall be measured with and without the ATU-C and ATU-R connected to the test loop. The impedance of the test equipment at the PSTN interface shall be 900 ohms, and the impedance at the POTS interface shall be 600 ohms.

The increase in insertion loss at 1004 Hz on any of the test loops, due to the addition of the splitters shall be ≤ 1.0 dB.

10.2.1.2 Attenuation distortion

The variation of insertion loss with frequency of the combination of both POTS splitters shall be measured using the test setup shown in figure 24. The impedance of the test equipment at the PSTN interface shall be 900 ohms, and the impedance of the test equipment at the POTS interface shall be 600 ohms. The added attenuation distortion of the combined POTS splitters relative to loss at 1 kHz measured using each of the test loops identified above shall be not more than ± 1.0 dB at any frequency between 0.2 kHz and 3.4 kHz.

10.2.1.3 Delay distortion

The delay distortion of the POTS splitters shall be measured using the test setup of figure 24. The increase in envelope delay distortion between 0.6 kHz and 3.2 kHz caused by the two POTS splitters in each of the test loops shall be less than 200 µS.

10.2.1.4 Return loss

The ERL, SRL-low and SRL-high shall be measured at the PSTN and POTS interfaces, for each of the 10 loops (except the null loop), under the following conditions:

– at the PSTN interface with both the ATU-C and ATU-R splitters installed and the ATU-R terminated in ZTR;
– at the PSTN interface with the ATU-C splitter installed and the ATU-R terminated in ZTR;
– at the POTS interface with both splitters installed and the ATU-C terminated in ZTC;
– at the POTS interface with the ATU-R splitter installed and the ATU-C terminated in ZTC.

The ERL, SRL-low and SRL-high for each of these conditions shall exceed the values contained in table 29 for each loop.

Table 29 - Minimum voice-band return losses at PSTN and POTS interfaces

Measurement Location	ATU-C Splitter	ATU-R Splitter	ERL (dB)	SRL-low (dB)	SRL-high (dB)
PSTN	in	in	8	5	5
PSTN	in	out	8	5	5
POTS	in	in	6	5	5
POTS	out	in	6	5	5

Furthermore, it is desirable that the mean values of the ERL, SRL-low and SRL-high over the full suite of ten loops be degraded as little as possible from the mean values with no splitters present. The permissible amount of degradation is for further study.

10.2.1.5 Noise and distortion

The distortion contributed by the two POTS splitters shall be measured using the test configuration of figure 24 and the null loop.

With an applied holding tone at –9 dBm, the Signal-to-C-notched noise ratio shall exceed 42 dB, and the second- and third-order intermodulation distortion products shall be at least 57 dB and 60 dB, respectively, below the received signal level.

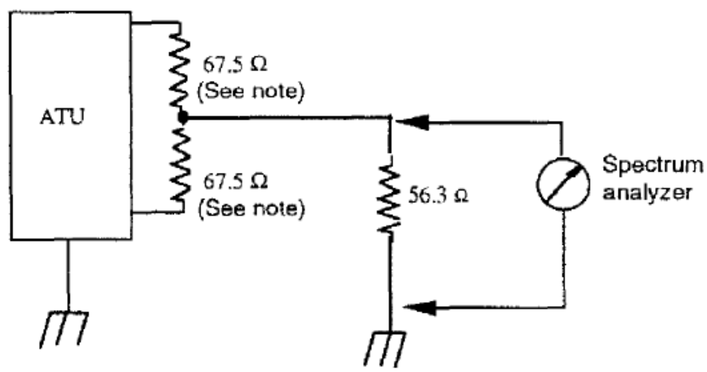
NOTE: While these measurements are often made with a holding tone level of -13 dBm, a level of -9 dBm is specified for this application because it represents the maximum allowed signal power from a voice-band modem onto a POTS line.

10.2.2 Longitudinal (common mode)

10.2.2.1 Longitudinal output voltage

The ATU-C shall present to the U-C interface, and similarly the ATU-R shall present to the U-R interface, a longitudinal component whose rms voltage in any 4 kHz band averaged in any 1 second period, is less than –50 dBv over the frequency range 100 Hz to 1 MHz.

Figure 25 defines a measurement method for longitudinal output voltage. For direct use of this test configuration, the ATU shall be able to generate a signal in the absence of a received signal. The ground reference for these measurements shall be the building or green wire ground at the ATU.



NOTE - These resistors shall be matched to better than 0.1% tolerance

Figure 25 – Measurement method for longitudinal output voltage

10.2.2.2 Longitudinal balance

Longitudinal balance at the PSTN and POTS interfaces shall be > 58 dB from 0.2 kHz to 1 kHz and >53 dB at 3 kHz, measured in accordance with IEEE Standard 455-1985.

10.3 ADSL band

10.3.1 Return loss

At the U-C and U-R reference points the nominal impedance in the ADSL band shall be 100 ohms. The return loss relative to 100 ohms in the frequency range from 30 –1100 kHz shall be ≥ 10 dB.

10.3.2 Longitudinal balance

Longitudinal balance at the U-C and U-R interfaces shall be > 40 dB over the frequency range 20 kHz to 1100 kHz with the PSTN and POTS interfaces terminated with ZTC and ZTR respectively. Longitudinal balance is given by the equation

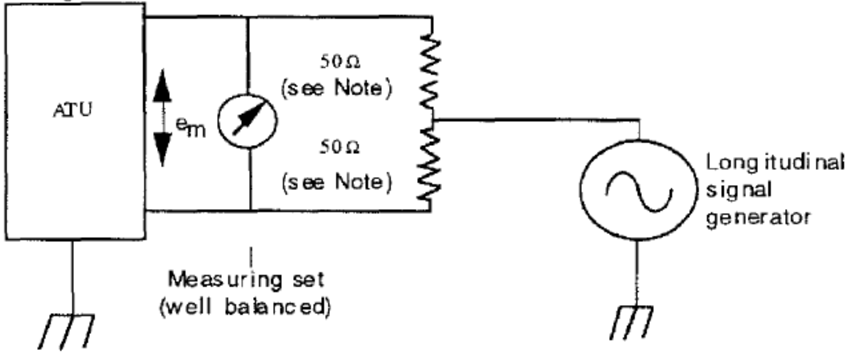
$$LBal = 20 \log \left| \frac{e_l}{e_m} \right| \text{dB}$$

where:

e_l = the applied longitudinal voltage (referenced to the building or green wire ground of the ATU);

e_m = the resultant metallic voltage appearing across a terminating resistor.

Figure 26 defines a measurement method for longitudinal balance in the ADSL band. For direct use of this test configuration, measurements shall be performed with the ATU powered up but inactive, driving 0 Volts.



NOTE - These resistors to be matched to better than 0.03% tolerance

Figure 26 – Measurement method for longitudinal balance above 25 kHz

10.4 ADSL noise interference into the POTS circuit

10.4.1 Steady state noise

The idle channel noise on the POTS circuit shall not exceed 18 dBrnC at either the POTS or the PSTN interfaces with the ADSL system installed whether operating or not operating.

The power at any single frequency less than 15 kHz as measured by test equipment with a bandwidth of 30 Hz shall not exceed the greater of 0 dBrn or 10 dB below the measured idle channel noise.

10.4.2 Impulse noise

During initialization and operation of the ADSL system, with no holding tone applied to the circuit under test, there shall be no more than fifteen counts in fifteen minutes at a threshold of 47 dBrnC0 at either the PSTN or the POTS interface.

During initialization and operation of the ADSL system, with a −13 dBm0 holding tone at 1004 Hz applied
to the circuit under test, there shall be no more than fifteen counts in fifteen minutes at a threshold of 65 dBrnCO at either the PSTN or the POTS interface.

These impulse noise requirements shall be met with each of the test loops specified in 10.2.1 with the ADSL system forced to re-initialize once per minute during the test interval.

11 Operations and maintenance

11.1 Embedded operations channel (eoc) requirements

An embedded operations channel for communication between the ATU-C and ATU-R shall be used for in-service and out-of-service maintenance, and for the retrieval of a limited amount of ATU-R status information and ADSL performance monitoring parameters. The eoc may also be used in the future to extend maintenance and performance monitoring to the service module(s) at the customer premises. The eoc channel is shared with user channel synchronization control of the fast data buffer. This clause describes the eoc functions, protocol, and commands. Insertion of eoc frames within the ADSL data frames is described in 6.2 and 7.2.

11.1.1 eoc organization and protocol

The ADSL eoc is organized into eoc frames, which are transmitted within the synchronization control overhead of the fast data buffer, to allow the ATU-C (acting as master of the link) to invoke commands and the ATU-R (acting as slave) to respond to the commands.

When it is not required for synchronization control, crc, or fixed indicator bits, the "fast" byte of two successive ADSL frames, beginning with an even-numbered frame as described in 6.2 and 7.2, shall be used to transmit one eoc frame, consisting of 13 bits. For the allowable user data configurations (see 5.3), up to 32 eoc frames can be transmitted per ADSL superframe. The eoc channel rate will vary from some minimum rate that will be dependent on the vendor's synchronization control algorithm (to implement the synchronization control described in 6.2) to about 23.7 kbit/s.

The ATU-C, as master, determines the eoc rate of the ADSL link; therefore only one eoc frame shall be inserted in the upstream direction (by the ATU-R) for each received eoc frame. One exception to this is for the "dying gasp" message, which is the only autonomous message currently allowed from the ATU-R and is inserted as soon as upstream "fast" bytes are available.

The 13 bits of the eoc frame are defined in table 30. The assignment of these bits to positions within the "fast byte" is defined in 6.2 and 7.2. The eoc protocol states are defined in 11.1.4.

Table 30 - eoc bit functions

Bit Position	#Bits	Description	Notes
1,2	2	Address field	Can address 4 locations
3	1	Data (0) or opcode (1) field	Data-used for read/write
4	1	Byte parity field Odd (1) or even (0)	Multibyte transmission
5	1	Unspecified for ATU-C (set to 1) (see note) Autonomous ATU-R message (0) or ATU-R response to eoc protocol (1)	Reserved for future use at ATU-C Used by ATU-R to send "dying gasp"
6-13	8	Information field	58 opcodes, 8 bits data

NOTE - The only autonomous message currently defined for the ATU-R is the "dying gasp" (11.1.4.4). Other uses of the eoc5 bit are for further study.

11.1.2 eoc frame structure

The eoc frame shall contain 5 fields, defined in the following subclauses.

11.1.2.1 Address field

The two bits of the address field can address up to four locations. Only two locations are presently defined:

- 11 for the ATU-C;
- 00 for the ATU-R.

10 and 01 are reserved for future use.

11.1.2.2 Data or opcode field

A 1 in this field indicates that the information field of the current eoc frame contains data; a 0 that it contains an operation code for an ADSL eoc message.

11.1.2.3 Byte parity field

For the first byte of data that is to be either read or written, this bit shall be set to 1 to indicate "odd" byte. For the next byte, it is set to 0 to indicate "even" byte and so on, alternately. This bit helps to speed up multi-byte reads and writes of data by eliminating the need for intermediate opcodes to indicate to the far end that the previous byte was successfully received.

11.1.2.4 Unspecified bit (ATU-C) / ATU-R autonomous message field

At the ATU-C, this field is reserved for future use, and until specified otherwise shall be set to 1 in all eoc frames transmitted by the ATU-C. At the ATU-R, a 1 in this field shall designate that the current eoc frame is an eoc protocol response (slave) message; a 0 that it is an autonomous message that does not disturb the current state of the eoc protocol at either the ATU-C or the ATU-R. The only autonomous message currently defined for the ATU-R is the "dying gasp" (11.1.4.4).

11.1.2.5 Information field

Up to 58 different messages or 8 bits of binary or ASCII data may be encoded in the information field.

The message set is restricted to codes that provide a minimum Hamming distance of 2 between all opcodes, and a minimum distance of 3 between certain critical codes and all other codes.

11.1.3 eoc message sets

The ATU-C sends commands to the ATU-R to perform certain functions. Some of these functions require the ATU-R to activate changes in the circuitry (e.g., to send crc bits that are corrupt). Other functions that can be invoked are to read from and write into data registers located at the ATU-R. The data registers are used for reading status- or performance-monitoring parameters from the ATU-R, or for limited maintenance extensions to the CI wiring distribution network or service modules.

Some of these commands are "latching", meaning that a subsequent command shall be required to release the ATU-R from that state. Thus, multiple ADSL eoc-initiated actions can be in effect simultaneously. A separate command, "Return To Normal", shall be used to unlatch all latched states. This command is also used to bring the ADSL system to a known state, the idle state, when no commands are active in the ATU-R location. To maintain the latched state, the command "Hold State" shall be continually sent.

The ATU-C always issues the commands, and the ATU-R responds by acknowledging to the ATU-C that the message was received correctly.

11.1.3.1 eoc message set requirements

Messages that may be sent by the ATU-R and ATU-C in response to correctly received messages are:

– *Hold State:* This message shall be sent by the ATU-C to the ATU-R to maintain the ATU-R eoc processor and any active ADSL eoc-controlled operations (such as latching commands) in their present state;

– *Return to Normal (Idle Code):* This message releases all outstanding eoc-controlled operations (latched conditions) at the ATU-R and returns the ADSL eoc processor to its initial state. This code is also the message sent during idle states;

– *Unable to Comply Acknowledgment:* The ATU-R shall send this message when it receives an ADSL eoc message that it cannot perform either because it does not recognize or implement the command or because the command is unexpected, given the current state of the ADSL eoc interface. An example of an unexpected command is one that indicates that the information field contains data, but that was not preceded by a "Write Data" command;

– *Request Corrupt crc:* This message requests the ATU-R to send corrupt crcs to the ATU-C until canceled by the "Request End of Corrupt crc" or "Return to Normal" message. In order to allow multiple ADSL eoc-initiated actions to be in effect simultaneously, the "Request corrupt crc" command shall be latching;

– *Request End of Corrupt crc:* This message requests the ATU-R to stop sending corrupt crcs toward the ATU-C;

– *Notify Corrupted crc:* This message notifies the ATU-R that intentionally corrupted crcs will be sent from the ATU-C until cancellation is indicated by "Notify End of Corrupted crc" or "Return to Normal";

– *Notify End of Corrupted crc:* This message notifies the ATU-R that the ATU-C has stopped sending corrupted crcs;

– *Perform Self Test:* This message requests the ATU-R to perform a self test. The result of the self test is stored in a register at the ATU-R. After the ATU-R self test, the ATU-C reads the test results from the ATU-R register;

– *Write Data (Register #):* This message directs the ATU-R to enter the Data Write Protocol state and receive data in the register specified by the Opcode;

– *Read Data (Register #):* This message directs the ATU-R to enter the Data Read Protocol state to transmit data to the ATU-C from the register specified by the Opcode;

– *Next Byte:* This message is sent by the ATU-C in data read or data write mode after the ATU-R has acknowledged the previously sent read or write data command. This message is continually sent by the ATU-C when it is in the data read or data write mode, toggling bit four for multi-byte data, until all data has been read;

– *End of Data:* This message is sent by the ATU-C after it has sent all bytes of data to the ATU-R. This message is also sent by the ATU-R in response to a "Next Byte" message from the ATU- C that is received after all bytes have been read or written from the currently addressed ATU-R register;

– *Vendor Proprietary Opcodes:* Four opcodes have been reserved for vendor proprietary use. The ATU-C shall read the ID (identification) code register of the ATU-R to ensure compatibility between the ATUs before using proprietary opcodes;

– *Undefined Command Codes:* All command codes not defined are reserved for future use, and shall not be used for any purpose

11.1.3.2 eoc opcode messages

Table 31 - eoc opcode messages

(HEX)	Opcode meaning	Notes
01	Hold state	To continue sending corrupt crcs
F0	Return all active conditions to normal	Also used as "idle code"
02	Perform "self test"	Self test results are stored in register
04	Unable to comply (UTC)	Unrecognizable command
07	Request corrupt crc (see note)	
08	Request end of corrupt crc	
0B	Notify corrupt crc (see note)	
0D	Notify end of corrupt crc	
0E	End of data	
10	Next byte	
E7	Dying Gasp	Sent by ATU-R only
(20,23,25,26) (29,2A,2C,2F) (31,32,34,37) (38,3B,3D,3E)	Write data register numbers 0 through F	
(40,43,45,46) (49,4A,4C,4F) (51,52,54,57) (58,5B,5D,5E)	Read data register numbers 0 through F	
(19,1A,1C,1F)	Vendor proprietary protocols	
NOTE - Latching conditions		

The eoc opcode messages specified in table 31 guarantee a minimum Hamming distance of 2 (by requiring odd parity for all but two critical codes) between all opcodes, a minimum Hamming distance of 3 between the "Return to Normal" (or "idle") code and all other codes, and a minimum Hamming distance of 3 between the "Dying Gasp" code and all other codes.

The following hexadecimal codes, which still maintain a minimum Hamming distance of 2, shall not be used unless specified at some future time: 13, 15, 16, 80, 83, 85, 86, 89, 8A, 8C, 8F.

11.1.3.3 Data registers in the ATU-R

Table 32 summarizes the ATU-R data registers and their applications.

Table 32 - ATU-R data registers

REG # (HEX)	USE	LENGTH	DESCRIPTION
0	Read (R)	6 bits	ID code (ATU-R): bits 0-3: vendor IDs 0 through F, bits 4,5: reserved for future use (set to 0)
1	R	6 bits	version number : bits 0-3: version numbers 0 through F, bits 4,5: reserved for future use (set to 0)
2	R	256 bits	Serial #
3	R	1 byte	Self test results
4	Read/Write (R/W)	Vendor Defined	Vendor defined
5	R/W	Vendor Defined	Vendor defined
6	R	1 byte	line attenuation
7	R	1 byte	Estimated margin
8	R	30 bytes	ATU-R Configuration (Note 1) : one byte each for B_F(AS0), B_I(AS0), B_F(AS1), B_I(AS1), B_F(AS2), B_I(AS2), B_F(AS3), B_I(AS3), B_F(LS0), B_I(LS0), B_F(LS1), B_I(LS1), B_F(LS2), B_I(LS2) FS(LS2) (downstream), B_F(LS0), B_I(LS0), B_F(LS1), B_I(LS1), B_F(LS2), B_I(LS2) FS(LS2) (upstream), R_{dsf}, R_{dsi}, S, I (downstream), R_{usf}, R_{usi}, S, I (upstream)
9	R	4 bits	Service module maintenance indicators (Note 2): bit 0: SM downstream sync bit 1: SM downstream no sync bit 2: SM upstream sync bit 3: SM upstream no sync
A - F	reserved	reserved	

NOTES

1 ATU configuration parameter set (B_F( ), B_I( ), FS(LS2), R_{dsf}, R_{dsi}, R_{usf}, R_{usi}, S, I) are defined in 6.2 and 7.2.

2 SM sync–no sync indicators defined in 11.5

3 Registers A through F are reserved for future use; ATU-R shall respond UTC (unable to comply) if requested to read or write one of these registers.

11.1.4 eoc protocol states

The ADSL eoc protocol operates in a repetitive command and response mode. The ATU-C acts as the master and issues commands; the ATU-R acts as slave, and responds to the commands issued by the ATU-C. Three identical properly-addressed consecutive messages shall be received before an action is initiated. Only one command and only three or fewer messages, under the control of the ATU-C, shall be outstanding (i.e., unacknowledged) at any one time.

(This restriction on the number of messages guarantees that an ATU-R with fewer opportunities to insert eoc frames into the upstream path will be able to acknowledge all eoc messages from the ATU-C).

Three types of responses are allowed from the ATU-R; therefore three command and response protocol states are allowed on the ADSL eoc. The three states are:

- message/echo-response protocol state;
- message/unable-to-Comply-response protocol state;
- message/data-response protocol state.

In addition to these three states, one autonomous message shall be allowed from the ATU-R to the ATU-C to indicate "dying gasp". This message does not change the protocol state, nor does it count as a response to any ATU-C message; however, other actions (e.g., an automatic reset at the ATU-C) taken as a result of receiving this message may lead to a change of state (e.g., back to idle).

The eoc protocol shall enter the Message/Echo-response protocol state when the ATUs transition from the initialization and training sequence to steady state transmission. The ATU-C shall continuously send an appropriately addressed message. In order to cause the desired action in the addressed location, the ATU-C shall continue to send the message until it receives three identical consecutive eoc frames from the addressed location. The command and response protocol for that message shall be completed before a new message, which may induce a different protocol state in the ATU-R, may be issued.

11.1.4.1 Message / echo-response protocol state

To initiate an action at the ATU-R, the ATU-C shall begin sending eoc messages with the Data/opcode set to 0, and with the appropriate message opcode in the information field.

The ATU-R shall initiate action when, and only when, three identical, consecutive, and properly addressed eoc frames that contain a message recognized by the ATU-R have been received. The ATU-R shall respond to all received messages. The response shall be an echo of the received ADSL eoc message. The combination of the ATU-C sending an ADSL eoc frame and the ATU-R echoing the frame back comprises the message/echo-response protocol state.

For the ATU-C to confirm correct reception of the message by the ATU-R, the message / echo-response ADSL eoc protocol state shall be repeated until the master node receives three identical and consecutive echoes. This serves as an implicit acknowledgment to the ATU-C that the ATU-R has correctly received the transmitted message and is acting on it. This completes the Message / Echo-response protocol mode.

Because eoc frames are inserted into ADSL frames only when the "fast byte" is available, the amount of time it takes to complete a message under error-free conditions will depend on the vendor's synchronization control algorithm, on the number of signals allocated to the fast buffer, and on the rates of those signals.

The ATU-C may continuously send the activating message after the receipt of the three valid echoes, or alternatively, it may switch to sending the "Hold State" message. If the message was one of the latching commands, then the ATU-R shall maintain the commanded condition until the ATU-C issues the appropriate command that ends the specific latched condition or until the ATU-C issues the "Return to Normal" command (at which time all latched conditions in the ATU-R shall be terminated).

11.1.4.2 Message / unable-to-comply response protocol state

When the ATU-R does not support a message that it has received three times identically and consecutively, it shall respond with the Unable-To-Comply (UTC) ADSL eoc response message

with its own address in lieu of a third identical and consecutive echo. In this manner the ATU-R will switch to the message / UTC-response protocol state.

The transmission by the ATU-R and reception by the ATU-C of three identical, consecutive, properly-addressed Unable-To-Comply messages constitutes notification to the ATU-C that the ATU-R does not support the requested function, at which time the ATU-C may abandon its attempt.

11.1.4.3 Message / data-response protocol state

The ATU-C can either write data into, or read data from the ATU-R memory.

11.1.4.3.1 Data read protocol

To read data from the ATU-R, the ATU-C shall send an appropriate read opcode message to the ATU-R that specifies the register to be read. After receiving three identical and consecutive acknowledgments, the ATU-C shall request the first byte to be sent from the ATU-R by sending "Next Byte" messages with bit four set to 1, indicating a request for an "odd" byte. The ATU-R shall respond to these "Next Byte" messages by echoing them until it has received three such messages consecutively and identically. Beginning with the third such reception, the ATU-R shall respond by sending the first byte of the register in the information field of an ADSL eoc frame with bit four set to 1 to indicate "odd byte" and with bit 3 set to 0 to indicate that the eoc frame is a data frame (as opposed to a frame that contains an opcode in the information field). The ATU-C continues to send the "Next Byte" message with bit four set to "odd byte", and the ATU-R continues to respond with a data frame containing the first byte of data and bit four equal to "odd byte", until the ATU-C has received three consecutive and identical data frames with bit four set to "odd byte".

If there is more data to be read, the ATU-C shall request the second byte of data by sending "Next Byte" messages with bit four set to 0 ("even byte"). The ATU-R echoes all messages received until three such "Next Byte" messages have been received, and on the third consecutive and identical "Next Byte" message, the ATU-R starts sending data frames containing the second byte of the register with bit four set to 0. The ATU-C continues to send the "Next Byte" message with bit four set to "even byte", and the ATU-R continues to respond with a data frame containing the identical data frames with bit four set to "even byte".

The process continues for the third and all subsequent bytes with the value of bit four toggling from "odd byte" to "even byte" or vice versa, on each succeeding byte. Each time bit four is toggled, the ATU-R shall echo for two correct frames, and starts sending the data frame on the third reception. The process ends only when all data in the register has been read.

To continue reading data, once the ATU-R is in the data read mode, the only message that the ATU-C is allowed to send is the "Next Byte" message with bit four toggling. To end the data read mode abnormally, the ATU-C shall send either "Hold State" or "Return to Normal", depending on whether any latched states are to be retained. If the ATU-R receives any other message three times consecutively and identically while it is in data read mode, the it shall go into a UTC mode.

If, after all bytes have been read from the ATU-R register, the ATU-C continues to send the "Next Byte" message with bit four toggled, then the ATU-R shall send an "End of Data" message (with bit three set to 1 indicating opcode).

The data read mode ends either when the ATU-C has received the last requested data byte three times consecutively and identically, or when the ATU-C has received three consecutive "End of Data" messages with bit three set to *1*. The ATU-C shall then switch over to a known state with the "Hold State" or "Return to Normal" message, and the ATU-R shall release the register and end the data read mode.

11.1.4.3.2 Data write protocol

To write data to the ATU-R's memory, the ATU-C shall send a "Write Data" opcode message to the ATU-R that specifies the register to be written. When the ATU-R acknowledges with three consecutive echo messages, the ATU-C shall send the first byte of data. The ATU-R shall acknowledge the receipt of the byte with an echo of the message. After the ATU-C is satisfied with three identical and consecutive correct echo responses, it shall start sending the next byte of data. Each time the ATU-C receives three identical and consecutive correct data echo responses, it shall switch to sending the next byte of data. It shall also toggle the "odd/even" bit accordingly. ("Next Byte" messages are not used in the Data Write mode). The ATU-C shall end the write mode with the "End of Data" message indicating to the ATU-R to release the register and end the data write mode.

11.1.4.4 "dying gasp"

When circuits in the ATU-R detect that electrical power has been shut off, the ATU-R shall insert eoc frames into the ADSL upstream data to implement a "dying gasp". The "dying gasp" eoc frames shall have bit 5 set to 0 to indicate autonomous message, bit 3 set to 1 to indicate opcode, and shall contain the "dying gasp" opcode (see table 31) in the information field. At least six of these frames are inserted in the next (twelve) available ADSL upstream "fast" bytes beginning with an even-numbered frame, regardless of the number of eoc frames received in the downstream channel.

Sending the "dying gasp" shall not cause the ATU-R to change the eoc protocol state, nor shall receiving it cause the ATU-C to immediately change state.

11.2 In-service performance monitoring and surveillance

The following terminology is used in this standard (see figure 27):

– *Near-end:* Near-end means performance of the loop-side received signal at the input of the ATUs;

– *Far-end:* Far-end means performance of the downstream loop-side received signal at the input of the ATU-R, where this performance is reported to the ATU-C in upstream overhead indicators (see figure 27). Far-end also means performance of the upstream loop-side received signal at the input of the ATU-C, where this performance is reported to the ATU-R in downstream overhead indicators; this case is a mirror image of the above;

– *Primitives:* Primitives are basic measures of performance, usually obtained from digital signal line codes and frame formats, or as reported in overhead indicators from the far-end. Performance primitives are categorized as events, anomalies and defects. Primitives may also be basic measures of other quantities (e.g., ac or battery power), usually obtained from equipment indicators;

– *Events:* Events are bit error related primitives that do not affect service performance (fec and fecc);

– *Anomalies:* Anomalies are bit error related primitives that affect service performance (crc and febe);

– *Defects:* Defects are signal or framing related primitives that are more disruptive to service than anomalies (los, sef, rdi).

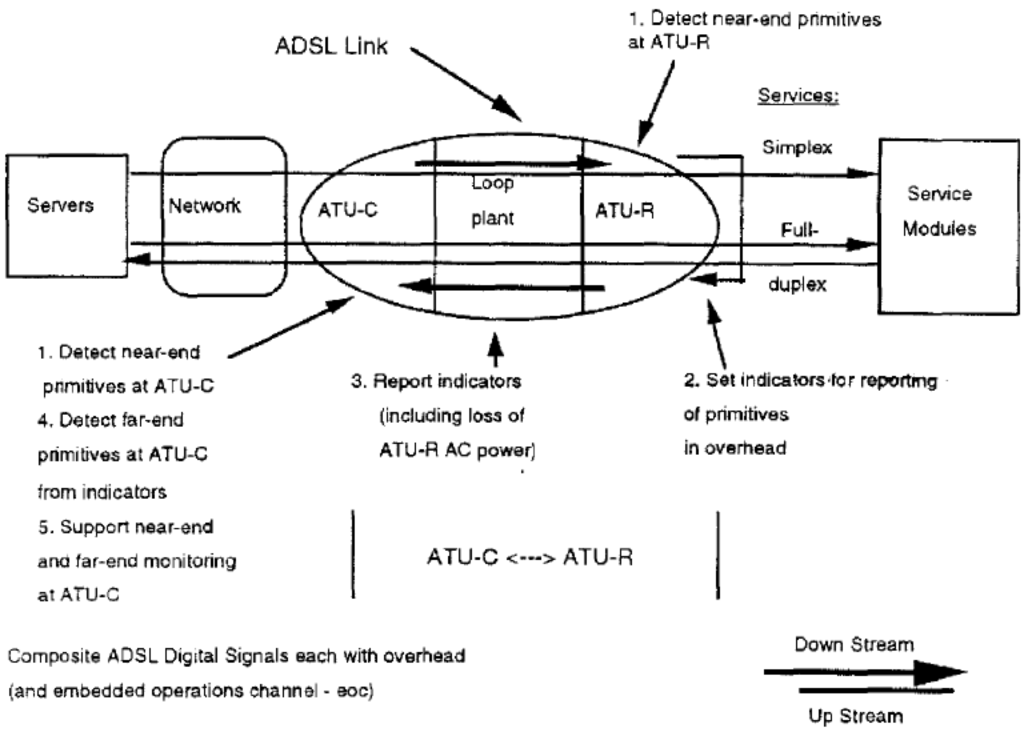


Figure 27 —In-service surveillance of the ADSL link shown from the standpoint of the ATU-C

11.2.1 Digital transmission related primitives

11.2.1.1 Near-end events

Two near-end events are defined:

– *Forward error correction (fec)-i:* An fec-i event occurs when a received FEC code for the interleaved data stream indicates that errors have been corrected;

– *Forward error correction (fec)-ni:* An fec-ni event occurs when a received FEC code for the non-interleaved data stream indicates that errors have been corrected.

11.2.1.2 Far-end events

Similarly, two far-end events are defined:

– *Far-end forward error correction (ffec)-i:* ffec-i shall be reported by the fecc-i indicator, which is coded with one indicator bit (*1* indicating that no event is present in the previous superframe; 0 indicating that an event is present) in the overhead, and reported once per ADSL superframe.

– *Far-end forward error correction (ffec)-ni:* ffec-ni shall be reported by the fecc-ni indicator, which is coded and reported in the same way as an fecc-i.

11.2.1.3 Near-end anomalies

Two near-end anomalies are defined:

– *Cyclical redundancy check (crc)-i error:* A crc-i anomaly occurs when a received CRC-8 code for the interleaved data stream is not identical to the corresponding locally generated code.

– *Cyclical redundancy check (crc)-ni error:* A crc-ni anomaly occurs when a received CRC-8 code for the non-interleaved data stream is not identical to the corresponding locally generated code.

11.2.1.4 Far-end anomalies

Similarly, two far-end anomalies are defined:

– *Far-end block error (febe)-i:* A crc-i anomaly detected at the far-end shall be reported by the febe-i indicator, which is coded with one indicator bit (*1* indicating that no event is present in the previous superframe; *0* indicating that an event is present) in the overhead, and reported once per ADSL superframe;

– *Far-end block error (febe)-ni:* A crc-ni anomaly detected at the far-end shall be reported by the febe-ni indicator, which is coded and reported in the same way as an febe-i.

11.2.1.5 Near-end defects

Two near-end defects are defined:

– *Loss-of-signal (los):* A pilot tone reference power shall be established by averaging the ADSL pilot tone power for 0.1 sec. after the start of steady state data transmission (i.e., after initialization). A los defect then occurs when the received ADSL pilot tone power, averaged over a 0.1 s period, is 6 dB or more below the reference power. A los defect shall terminate when the received pilot tone power, averaged over a 0.1 s period is less than 6 dB below the reference;

– *Severely errored frame (sef):* A sef defect occurs when the content of two consecutively received ADSL synchronization symbols does not match the expected content. An sef defect terminates when the content of two consecutively received ADSL synchronization symbols matches the expected content.

11.2.1.6 Far-end defects

– *Loss-of-signal (los):* A los defect as detected at the far-end shall be reported by the los indicator, which is coded with one indicator bit (1 indicating that no defect is being reported; 0 indicating that a defect is being reported) in the overhead, and reported for six consecutive ADSL superframes.

A far-end los defect occurs when 4 or more out of 6 contiguous los indicators are received set to 0. A far-end los defect terminates when 4 or more out of 6 contiguously received los indicators are set to 1;

– *Remote defect indication (rdi):* An sef defect is reported by the rdi indicator, which is coded with one indicator bit (1 indicating that no event is present in the previous superframe; 0 indicating that an event is present) in the overhead, and reported once per ADSL superframe. A rdi defect occurs when a received rdi indicator is set to 0. A rdi defect terminates when a received rdi indicator is set to 1.

11.2.2 Other primitives

11.2.2.1 Other near-end primitives

Three other near-end primitives are defined:

– *Attenuation (atn):* An atn primitive is the difference in dB between the power received at the near-end and that transmitted from the far-end. Signal power in dBm is the sum of all active DMT subcarrier powers averaged over a 1 s period. An atn primitive is expressed as an integer number of dB ranging from a min.imum of 0 to a maximum of 60 dB, so as to correspond to a sensible range of atn;

– *Signal-to-Noise ratio (snr) margin:* An snr margin primitive represents the amount of increased noise (in dB) relative to the noise power that the system is designed to tolerate and still meet the target BER of 10^{-7}, accounting for all coding (e.g., Trellis code, FEC) gains included in the design. An snr margin primitive is expressed as an integer number of dB ranging from a minimum of x dB to a max. of y dB, with x and y for further study so as to correspond to a sensible range of SNR;

– *Loss-of-power (lpr):* An lpr primitive occurs when ATU power drops to a level equal to or below the manufacturer-determined minimum power level required to ensure proper operation of the ATU. An lpr primitive terminates when the power level exceeds the manufacturer-determined minimum power level.

11.2.2.2 Other far-end primitives

Similarly, three other far-end primitives are defined:

– *Attenuation (atn):* An atn primitive as detected at the far-end shall be reported by the atn indicator. A far end atn primitive occurs when one atn indicator is received with value not less than x and not more than y dB, with the values of x and y for further study. The atn indicator is reported in an eoc message;

– *Signal-to-noise Ratio (snr) margin:* An snr margin primitive as detected at the far-end shall be reported by the snr margin indicator in an eoc message. A far-end snr margin primitive occurs when one snr margin indicator is received with value not less than *x* and not more than *y* dB, with the values of *x* and *y* for further study;

– *Loss-of-power (lpr):* An lpr primitive as detected at the far-end shall be reported by the lpr indicator. A far-end lpr primitive occurs when 4 out of 6 contiguous lpr indicators are received. A far-end lpr primitive terminates if the near signal remains present, i.e., if the received 4 out of 6 contiguous lpr indicators are not followed by any near-end los defects in the next 0.5 s (see los defect definition in 11.2.1.5);

The lpr indicator is coded as an 8 bit emergency priority message in the ATU-R to ATU-C overhead, and is reported in the next 6 available outgoing eoc frames (see the eoc protocol for "dying gasp" in 11.1.4.4).

11.2.3 Failures and failure count parameters

11.2.3.1 Near-end failures and failure count parameters

At the ATU-R, near-end failures shall be manifested as LOS or LOF failure (e.g., red light), no failures (e.g., green light), and LPR (e.g., no lights); failure count parameters are optional.

The following near-end failures and failure count parameters are required at the ATU-C.

– *Loss-of-signal (LOS):* An LOS failure is declared after 2.5 ± 0.5 seconds of contiguous los defect, or, if los defect is present when the criteria for LOF failure declaration have been met (see LOF definition below). An LOS failure is cleared after 10 ± 0.5 seconds of no los defect. An LOS failure count is the number of occurrences of an LOS failure event,

where a failure event occurs when the failure is declared, and ends when the failure clears;

– *Loss-of-frame (LOF):* An LOF failure is declared after 2.5±0.5 seconds of contiguous sef defect, except when an los defect or failure is present (see LOS definition above). A LOF failure is cleared when LOS failure is declared, or after 10±0.5 seconds of no sef defect. An LOF failure count is the number of occurrences of an LOF failure event, where a failure event occurs when the failure is declared, and ends when the failure clears;

– *Loss-of-power (LPR):* An LPR failure is declared after the occurrence of an lpr primitive, followed by other to be determined conditions. This definition is under study. An LPR failure count is the number of occurrences of an LPR failure event, where a failure event occurs when the failure is declared, and ends when the failure clears.

11.2.3.2 Far-end failures and failure count parameters

The following far-end failures and failure count parameters are required at the ATU-C (ATU-R is at the far-end), and are optional at the ATU-R (ATU-C is at the far-end).

– *Loss-of-signal (LOS):* A far-end LOS failure is declared after 2.5 ± 0.5 seconds of contiguous far-end los defect, or, if far-end los defect is present when the criteria for LOF failure declaration have been met (see below). A far-end LOS failure is cleared after 10 ± .5 seconds of no far-end los defect. An LOS failure count is the number of occurrences of a LOS failure event, where a failure event occurs when the failure is declared, and ends when the failure clears;

– *Remote failure indication (RFI):* An RFI failure is declared after 2.5 ± 0.5 seconds of contiguous rdi defect, except when a far-end los defect or failure is present (see above). A RFI failure is cleared when far-end LOS failure is declared, or after 10 ± 0.5 seconds of no rdi defect. An RFI failure count is the number of occurrences of a RFI failure event, where a failure event occurs when the failure is declared, and ends when the failure clears;

– *Loss-of-power (LPR):* An LPR failure is declared after receiving a far-end lpr (dying gasp-like) primitive followed by 2.5 ± 0.5 seconds of contiguous near-end los defect. A LPR failure is cleared after 10 ± 0.5 seconds of no near-end los defect. An LPR failure count is the number of occurrences of a LPR failure event, where a failure event occurs when the failure is declared, and ends when the failure clears.

11.2.4 Quality-of-service (QOS) parameter

11.2.4.1 Near-end QOS parameter

The near-end errored-second (ES) parameter is a count of one-second intervals containing one or more crc-i or crc-ni anomalies, or one or more los or sef defects. It is required at the ATU-C, and is optional at the ATU-R.

11.2.4.2 Far-end QOS parameter

The far-end errored-second (ES) parameter is a count of one-second intervals containing one or more febe-i or febe-ni anomalies, or one or more far-end los or rdi defects. It is required at the ATU-C (ATU-R is at the far-end), and is optional at the ATU-R (ATU-C is at the far-end).

11.2.5 Test parameters

The attenuation (ATN) and signal-to-noise ratio (SNR) margin test parameters apply to on-demand test requests; e.g., to check for adequate physical media performance margin at acceptance and after repair verification, or at any other time following the execution of

initialization and training sequence of the ADSL system. ATN and SNR, as measured by the receivers at both the ATU-C and the ATU-R shall be externally accessible from the ATU-C, but they are not required to be continuously monitored.

11.2.5.1 Near-end test parameters

The following near-end test parameters are required at the ATU-C, and are optional at the ATU-R.

– *Attenuation (ATN):* An atn primitive is the difference in dB between transmitted and received signal power. Signal power in dBm is the sum of all active DMT subcarrier powers averaged over a 1 s period. An atn primitive is expressed as an integer number of dB ranging from a min. of x to a max. of y dB, x and y for further study so as to correspond to a sensible range of atn. An attenuation parameter is an instance of an atn primitive in response to an on-demand ATN test request;

– *Signal-to-noise ratio (SNR) margin:* An instance of an snr primitive (dB), in response to an on-demand SNR margin test request.

11.2.5.2 Far-end test parameters

The following far-end test parameters are required at the ATU-C (ATU-R is at the far-end), and are optional at the ATU-R (ATU-C is at the far-end).

– *Attenuation (ATN):* An instance of a far-end atn primitive (dB);

– *Signal-to-noise ratio (SNR) margin:* An instance of a far-end atn primitive (dB).

11.2.6 Performance monitoring functions

Near-end functions are required at the ATU-C, and are optional at the ATU-R. Far-end functions are required at the ATU-C (ATU-R is at the far-end), and are optional at the ATU-R (ATU-C is at the far-end).

11.2.6.1 Performance data storage

The following data registers are defined:

– A current 15 minute and a current 1 day register shall be provided for each near-end and for each far-end failure count and QOS parameter;
- A previous 15 minute and a previous 1 day register shall be provided for each near-end and for each far-end failure count and QOS parameter;
- A current and a previous register shall be provided for each near-end and for each far-end test parameter;
- A shared resource of 96 individual 15 minute registers per failure count and QOS parameter shall be assignable on-demand to a specific ADSL link. These registers shall not exceed about 10 % of the total dedicated failure count and QOS parameter memory resource requirements for all links over which this resource is shared;

NOTES
- Register sizes shall either accommodate maximum event counts or values, or have a minimum size of 16 bits;
- Register operation (e.g., pegging at the maximum value, resetting, setting of invalid data flag, etc.) shall comply with clause 9 of dpANS T1.231-1993;
- Register invalid data flags shall be set if the ATUs are powered down during all or part of the accumulation interval (15 minute or one day).

11.2.6.2 Performance data reporting

Performance data shall be reportable on demand (not scheduled) when queried by an operations entity.

11.3 Metallic testing

For further study

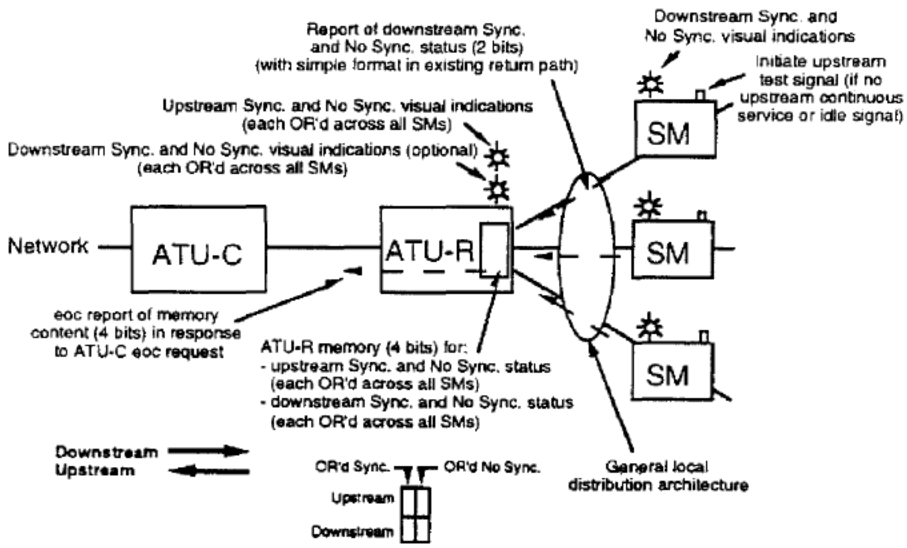
11.4 Out-of-service testing

For further study

11.5 Requirements to support OAM of the segment between ATU-R and SM

Requirements are expressed in terms of various indications for each direction of the segment between ATU-R and SM (downstream ATU-R to SM, and upstream SM to ATU-R). Downstream indications are also reported upstream from SMs to the ATU-R.

OAM of the ATU-R/ SM segment is null for SMs integrated in the ATU-R. For non-integrated SMs, requirements are as shown in figure 28.



NOTE - Visual indicators are shown as an example; not all implementations may provide them.

Figure 28 — OAM capabilities for the segment between ATU-R and the service module

11.5.1 SM requirements

The requirements for the service module (SM) are:

a) It shall detect separate downstream sync and no sync conditions. No sync is detected after 2.5 ± 0.5 seconds of persistent inability to acquire sync. Sync is detected after sync acquisition followed by 10 ± .5 seconds of persistent retention of sync;

b) It shall provide downstream sync and no sync indications, with corresponding interpretations. Exemplary interpretations are shown in table 33;

c) It shall report separate downstream sync and no sync status from SM to ATU-R (2 bits) in a simple format (for further study) on an existing return path (for further study) (e.g., control channel). For a single SM, the 2 bits shall have the interpretation specified in table 34. These interpretations are consistent with the indications in SM requirement (b) above.

Table 33 - Sync and no sync interpretation (downstream)

Sync	No sync	Interpretation
off	off	SM not powered
off	on	SM powered but not synchronized
on	off	SM synchronized
on	on	Invalid

Table 34 - Sync and no sync interpretation for single SM

Sync bit	No sync bit	Interpretation
0	0	SM not powered
0	1	SM powered but not synchronized
1	0	SM synchronized
1	1	Invalid

d) For services with upstream signals to which the ATU-R cannot continuously synchronize, the SM shall be able to send either an idle signal, or a locally-initiated test signal to the ATU-R for a (for further study) (e.g., 5) minute time-out period. The formats of these signals shall enable the ATU-R to synchronize to them in the same manner as for upstream service signals;

e) It shall be able to send a control channel (CC) acknowledge (ACK) message to the network in response to a CC query message from the network. Message formats are for further study.

11.5.2 ATU-R requirements

The requirements for the ATU-R are:

a) It shall detect separate upstream sync and no sync conditions (see requirement (d) below). No sync is detected after 2.5 ± 0.5 seconds of persistent inability to acquire sync. Sync is detected after sync acquisition followed by 10 ± 0.5 seconds of persistent retention of sync. Sync conditions from all SMs shall be logically OR'd into 1 bit, and no sync conditions from all SMs shall be logically OR'd into another bit;

b) It shall store the upstream OR'd sync. and OR'd no sync status (2 bits). For multiple SMs, the two bits shall have the interpretation specified in table 35;

Table 35 - Sync and no sync interpretation for multiple SMs

Sync bit	No sync bit	Interpretation
0	0	No SMs powered
0	1	At least 1 SM powered but not synchronized
1	0	At least 1 SM synchronized
1	1	Some SMs synchronized, others powered but not synchronized

c) It shall provide upstream OR'd sync and OR'd no sync indications (see requirement (d) below), consistent with the bit interpretations in ATU-R requirement (b) above. One example is:

Sync	No. Sync.	Interpretation
off	off	No SMs powered
off	on (e.g., red)	At least 1 SM powered but not synchronized
on (e.g., green)	off	At least 1 SM synchronized
on (e.g., green)	on (e.g., red)	Some SMs synchronized, others powered but not synchronized

d) Sync and no sync indications in ATU-R requirements (a) to (c) in this list apply to upstream service signals to which the ATU-R can continuously synchronize. Otherwise, an upstream idle signal, or the test signal in SM requirement (d) of 11.5.1 above shall be detected. With upstream idle signals, ATU-R detection, storage and indications and interpretations are as per ATU-R requirements (a) to (c) above. The same is true with the upstream test signal, during the time the test signal is being sent;

e) It shall detect separate downstream sync and no sync status reports from SMs, and logically OR each across all SMs, where OR'ing is as described in ATU-R requirement (a) in this list;

f) It shall store the downstream OR'd sync and OR'd no sync status (2 bits). For multiple SMs, the 2 bits shall have the same interpretation as for the upstream case in ATU-R requirement (b) in this list;

g) It shall provide downstream OR'd sync and OR'd no sync indications consistent with ATU-R requirement (c) in this list;

h) In response to an eoc request message from the ATU-C, it shall send a single eoc report of the upstream and downstream OR'd sync and OR'd no sync status to the ATU-C (4 bits).

11.5.3 ATU-C requirements

As per the ATU-R requirement 11.5.2(h), when requested by the network, the ATU-C shall be able to send an eoc message to retrieve the upstream and downstream OR'd sync and OR'd no sync status (4 bits), and to receive the corresponding eoc status report from the ATU-R.

12 Initialization

12.1 Overview

12.1.1 Basic functions of initialization

ADSL transceiver initialization is required in order for a physically connected ATU-R and ATU-C pair to establish a communications link. Establishment may be initiated by the ATU-C or the ATU-R as follows:

– An ATU-C, after power-up or loss of signal, and an optional self-test, may transmit activation tones (12.2) and await a response from the ATU-R (12.3.3). It shall make no more than two attempts; if no response is received it shall wait for an activation request from the ATU-R (12.3.1) or an instruction from the network to retry.

– An ATU-R, after power-up and an optional self-test, may repeatedly transmit activate request (12.3). If, however, the ATU-R receives C-TONE it shall remain silent for approximately one minute (12.3.2), unless it detects an activation signal (12.2.2).

In order to maximize the throughput and reliability of this link, ADSL transceivers shall determine certain relevant attributes of the connecting channel and establish transmission and processing characteristics suitable to that channel. The time line of figure 29 provides an overview of this process. In figure 29 each receiver can determine the relevant attributes of the channel through the transceiver training and channel analysis procedures. Certain processing and transmission characteristics can also be established at each receiver during this time. During the exchange process each receiver shares with its corresponding far-end transmitter certain transmission settings that it expects to see. Specifically, each receiver communicates to its far-end transmitter the number of bits and relative power levels to be used on each DMT sub-carrier, as well as any messages and final data rates information. For highest performance these settings shall be based on the results obtained through the transceiver training and channel analysis procedures.

ATU-C

Activation and acknowledgment (12.2)	Transceiver training (12.4)	Channel analysis (12.6)	Exchange (12.8)

ATU-R

Activation and acknowledgment (12.3)	Transceiver training (12.5)	Channel analysis (12.7)	Exchange (12.9)

time →

Figure 29 — Overview of initialization

Determination of channel attribute values and establishment of transmission characteristics requires that each transceiver produce, and appropriately respond to, a specific set of precisely-timed signals. This clause describes these initialization signals, along with the rules that determine the proper starting and ending time for each signal. This description is made through the definition of initialization states in which each transceiver will reside, and the definition of initialization signals that each transceiver will generate.
A state and the signal generated while in that state have the same name, which may sometimes, for clarity, be prefixed by "state" or "signal".

The sequence of generated downstream and upstream signals for a successful initialization procedure is shown by the time-lines of figures 30–33. The dashed arrow indicates that the change of state is caused by a successful reception of a specific signal. For example, in figure 32

ATU-R shall stay in state R-REVERB3 until it finishes receiving C-CRC2, at which point it shall move to R-SEGUE2 after an appropriate delay (see 12.7.2).

The description of a signal will consist of three parts:

– The first part is a description of the voltage waveform that the transmitter shall produce at its output when in the corresponding state

The output voltage waveform of a given initialization signal is described using the DMT transmitter reference model shown in figure 2. Figure 2 is not a requirement or suggestion for building a DMT transmitter. Rather, it is a model for facilitating accurate and concise DMT signal waveform descriptions. In figure 2 X_k is DMT sub-carrier k (defined in the frequency domain), and x_k is the kth IDFT output sample (defined in the time domain). The DAC and analog processing block of figure 2 construct the continuous transmit voltage waveform corresponding to the discrete digital input samples. More precise specifications for this analog block arise indirectly from the analog transmit signal linearity and power spectral density specifications of 10.1. The use of figure 2 as a transmitter reference model allows all initialization signal waveforms to be described through the sub-carrier sequence X_{kn} required to produce that signal. Allowable differences in the characteristics of different digital to analog and analog processing blocks will produce somewhat different continuous-time voltage waveforms for the same initialization signal. However, a compliant transmitter will produce initialization signals whose underlying DMT sub-carrier sequences match exactly those provided in the signal descriptions of 12.2 to 12.9;

– The second is a statement of the required duration, expressed in DMT symbol periods, of the signal. This signal duration may be a constant or may depend upon the detected state of the far end transceiver. The duration of a single DMT symbol period depends on whether the cyclic prefix is being used; some initialization signals contain a cyclic prefix, and some do not. ATU-C signals up to and including C-SEGUE1 are transmitted without a cyclic prefix; those from C-RATES1 on are transmitted with a prefix. Similarly, ATU-R signals up to and including R-SEGUE1 do not use a prefix; those from R-REVERB3 on do. The duration of any signal in seconds is therefore the defined number of symbol periods times the duration of the symbol being used;

– The third part of a signal's description is a statement of the rule specifying the next state.

12.1.2 Transparency to methods of separating upstream and downstream signals.

Manufacturers may choose to implement this standard using either frequency-division-multiplexing (FDM) or echo canceling (EC) to separate upstream and downstream signals. The initialization procedure described here ensures compatibility between these different implementations by specifying all upstream and downstream control signals to be in the appropriate, but narrower, frequency bands that would be used by an FDM transceiver, and by defining a time period during which an EC transceiver can train its echo canceler.

12.1.3 Resetting during initialization and data transmission

If errors or malfunctions are detected or timeout limits are exceeded at various points in the initialization sequence, the ATU-C and ATU-R shall return to the initial states C-QUIET1 and R-ACT-REQ, respectively, for retraining. Furthermore, some errors detected during data transmission (i.e., after a successful initialization) may also require retraining. An example of an overall state diagram is shown in annex A, but the specific retraining procedures are for further study.

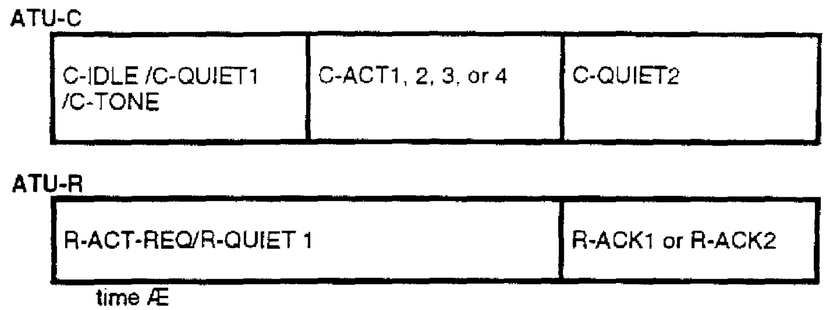


Figure 30 – Timing diagram of activation and acknowledgment (12.2-12.3)

12.2 Activation and acknowledgment - ATU-C

A host controller may be used to monitor the ATU-C activities and keep track of the state of the ATU-C if errors or malfunctions occur that require resetting to C-QUIET1, and retraining.

12.2.1 Pre-activate states

There are three mandatory pre-activation states at the ATU-C:

- C-QUIET1;
- C-IDLE;
- C-TONE.

The transitions between these and other vendor-optional states are shown in figure A.1, and described in Appendix A.

12.2.1.1 C-QUIET1

Upon power-up and after an optional self-test the ATU-C shall enter state C-QUIET1.

NOTE - QUIET and IDLE signals are defined as zero output voltage from the DAC of figure 2.

When the ATU-C is in C-QUIET1, either a command from the host controller or a successful detection of R-ACT-REQ (defined as detecting 128 consecutive symbols of active R-ACT-REQ signal followed by silent symbols) shall cause it to go to state C-ACT (see 12.2.2). To ensure full compatibility between FDM and EC systems, the ATU-C transmitter shall remain in state C-QUIET1 until the ATU-C receiver no longer detects the R-ACT-REQ signal. (i.e., detects the first symbol of R-QUIET1).

Alternatively, the host controller may command the ATU-C to enter C-IDLE.

12.2.1.2 C-IDLE

The ATU-C shall enter C-IDLE from C-QUIET1 in response to a host command. The difference between states C-QUIET1 and C-IDLE is that the ATU-C receiver reacts to R-ACT-REQ in C-QUIET1, but ignores it in C-IDLE.

If R-ACT-REQ is detected while in C-IDLE state, the host controller may elect to go to state C-TONE.

The ATU-C shall stay in C-IDLE indefinitely until the host controller issues the appropriate command to go to either state C-TONE (12.2.1.3), C-QUIET1 (12.2.1.1), C-ACT (12.2.2), or C-SELFTEST.

NOTE – C-SELFTEST is not defined herein; it is a vendor-option that does not affect compatibility.

12.2.1.3 C-TONE

The ATU-C shall transmit C-TONE to instruct the ATU-R not to transmit R-ACT-REQ. C-TONE is a single frequency sinusoid at $f_{C\text{-}TONE}$ = 310.5 kHz.

Referring to figure 2, C-TONE is defined as

$$X_k = \begin{cases} 0, k \neq 72, 0 \leq k \leq 256 \\ A_{C-TONE}, k = 72 \end{cases}$$

where $A_{C\text{-}TONE}$ shall be such that the transmit power level is –4 dBm (approximately –40 dBm/Hz over 4.3125 kHz) for the first 64 symbols, and –28 dBm for the second 64 symbols. This signal shall be transmitted for 128 consecutive symbols, and no cyclic prefix is used. C-IDLE immediately follows C-TONE.

12.2.2 C-Activate

To allow for inter-operability between FDM and EC systems, and among different vendors with different implementation of such systems, four activate signals, C-ACT1 to C-ACT4 are defined. These shall be used to distinguish different system requirements for loop timing and use of a pilot tone. These four signals are mutually exclusive; any given ATU-C shall transmit one and only one. Throughout the remainder of this document the generic term C-ACT will refer to the appropriate state and signal.

Loop timing is defined as the combination of the slaving of an ADC clock to the received signal (i.e., to the other transceiver's DAC clock), and tying the local DAC and ADC clocks together. Only one of the two transceivers can perform loop timing.

12.2.2.1 C-ACT1

The ATU-C shall transmit C-ACT1 to initiate a communication link to the ATU-R when the ATU-C will perform loop-timing, and the ATU-C cannot accept a pilot during R-QUIET3/R-PILOT1.

C-ACT1 is a single frequency sinusoid at $f_{C\text{-}ACT1}$ = 207 kHz. Referring to figure 2, C-ACT1 is defined by

$$X_k = \begin{cases} 0, k \neq 48, 0 \leq k \leq 256 \\ A_{C-ACT1}, k = 48 \end{cases}$$

where $A_{C\text{-}ACT1}$ shall be such that the transmit power level is –4 dBm (approximately –40 dBm/Hz over 4.3125 kHz) for the first 64 symbols, and –28 dBm for the second 64 symbols. This signal shall be transmitted for 128 consecutive symbols without a cyclic prefix. C-QUIET2 immediately follows C-ACT1.

12.2.2.2 C-ACT2

The ATU-C shall transmit C-ACT2 to initiate a communication link to the ATU-R when the ATU-C will not perform loop-timing, and the ATU-C cannot accept a pilot during R-QUIET3/R-PILOT1.

C-ACT2 is a single frequency sinusoid at $f_{C\text{-}ACT2}$ = 189.75 kHz, defined by

$$X_k = \begin{cases} 0, k \neq 44, 0 \leq k \leq 256 \\ A_{C-ACT2}, k = 44 \end{cases}$$

The level and duration of C-ACT2 shall be the same as those of C-ACT1. C-QUIET2 immediately follows C-ACT2.

12.2.2.3 C-ACT3

The ATU-C shall transmit C-ACT3 to initiate a communication link to the ATU-R when the ATU-C will perform loop-timing , and the ATU-C requests a pilot from the ATU-R during R-QUIET3/R-PILOT1. The decision whether to transmit R-PILOT1 is at the discretion of the vendor of the ATU-R.

C-ACT3 is a single frequency sinusoid at $f_{C\text{-}ACT3}$ = 224.25 kHz, defined by

$$X_k = \begin{cases} 0, k \neq 52, 0 \leq k \leq 256 \\ A_{C-ACT3}, k = 52 \end{cases}$$

The level and duration of C-ACT3 shall be the same as those of C-ACT1.

12.2.2.4 C-ACT4

The ATU-C shall transmit C-ACT4 to initiate a communication link to the ATU-R when the ATU-C will not perform loop-timing, and the ATU-C requests a pilot from the ATU-R during R-QUIET3/R-PILOT1. The decision whether to transmit R-PILOT1 is at the discretion of the vendor of the ATU-R.

C-ACT4 is a single frequency sinusoid at $f_{C\text{-}ACT4}$ = 258.75 kHz, defined by

$$X_k = \begin{cases} 0, k \neq 60, 0 \leq k \leq 256 \\ A_{C-ACT4}, k = 60 \end{cases}$$

The level and duration of C-ACT4 shall be the same as those of C-ACT1.

12.2.3 C-QUIET2

The purpose of C-QUIET2 is to allow the detection of R-ACK1 without the need to train the ATU-C echo canceller. The duration of C-QUIET2 is 128 symbols.

After C-QUIET2, ATU-C shall enter one of three states:

– *C-REVEILLE:* If the ATU-C detects R-ACK (see 12.3.3) it shall enter the state C-REVEILLE. Even if the ATU-C detects R-ACK in fewer than 128 symbols, the full duration of C-QUIET2 shall be maintained;
– *C-ACT:* If the ATU-C fails to detect R-ACK, and the state C-ACT has not been entered more than twice the ATU-C shall enter the state C-ACT. (A counter, which is reset upon entering C-QUIET1, should keep track of how many times ATU-C goes from C-QUIET2 and back to C-ACT);
– *C-QUIET1:* If the ATU-C does not detect R-ACK after returning twice to C-ACT it shall return to C-QUIET1.

12.3 Activation and acknowledgment - ATU-R

As in the ATU-C, a host controller may be used to monitor the ATU-R activities, and keep track of the state of the ATU-R if errors or malfunctions occur that require resetting to R-ACT-REQ.

12.3.1 R-ACT-REQ

R-ACT-REQ is used when it is desirable for the ATU-R to initiate a communication link to the ATU-C. One example is when a customer at ATU-R requests a service. R-ACT-REQ is transmitted after power-up and an optional successful self-test (see annex A). It is a single sinusoid at $f_{R\text{-}ACT\text{-}REQ}$ = 34.5 kHz, which, referring to figure 3, is defined by

$$X_k = \begin{cases} 0, k \neq 8, 0 \leq k \leq 32 \\ A_{R-ACT-REQ}, k = 8 \end{cases}$$

where $A_{R\text{-}ACT\text{-}REQ}$ shall be such that the transmit power level is –2 dBm (approximately –38 dBm/Hz over 4.3125 kHz) for the first 64 symbols and –22 dBm for the second 64 symbols, and $A_{R\text{-}ACT\text{-}REQ}$ = 0 for the next 896 symbols. This signal is transmitted for 1024 consecutive symbols.

The ATU-R shall stay in R-ACT-REQ indefinitely (i.e., transmitting the single tone signal for 128 symbols, then shutting the signal off for 896 symbols, and then repeating the process) until either

- a successful detection of C-ACT signal from the ATU-C, in which case the ATU-R shall enter R-ACK as soon as the full duration of C-ACT signal has been detected;
- a successful detection of C-TONE signal from the ATU-C, in which case the ATU-R shall enter R-QUIET1.

12.3.2 R-QUIET1

The duration of R-QUIET1 depends upon whether the ATU-R detects C-ACT:

- if the ATU-R detects C-ACT it shall immediately enter R-ACK;
- if it does not, it shall remain quiet for 240,000 symbols (approximately 60 seconds) and then re- enter R-ACT-REQ.

12.3.3 R-Acknowledge

R-Acknowledge is transmitted by the ATU-R, as an acknowledgement of the detection of C-ACT, in order to continue initiating a communication link to the ATU-C. Three acknowledge signals are defined. The uses of R-ACK1 and R-ACK2 are defined; the use of R-ACK3 is for further study. Throughout the rest of this document the generic term R-ACK will refer to the appropriate state and signal.

12.3.3.1 R-ACK1

R-ACK1 signifies that the ATU-R cannot accept a pilot during C-QUIET3, C-QUIET4, or C-QUIET5. It is a single sinusoid at $f_{R\text{-}ACK1}$ = 43.125 kHz defined by

$$X_k = \begin{cases} 0, k \neq 10, 0 \leq k \leq 32 \\ A_{R-ACK1}, k = 10 \end{cases}$$

where $A_{R\text{-}ACK1}$ shall be such that the transmit power level is –2 dBm (approximately –38 dBm/Hz over 4.3125 kHz) for the first 64 symbols and –22 dBm for the second 64 symbols. This signal shall be transmitted for 128 consecutive symbols. R-QUIET2 follows immediately after R-ACK1.

12.3.3.2 R-ACK2

R-ACK2 signifies that the ATU-R requires a pilot during C-QUIET3, C-QUIET4, and C-QUIET5. It is a single sinusoid at $f_{R\text{-}ACK2}$ = 34.5 kHz defined by_

$$X_k = \begin{cases} 0, k \neq 12, 0 \leq k \leq 32 \\ A_{R-ACK2}, k = 12 \end{cases}$$

The level and duration of R-ACK2 shall be the same as those of R-ACK1.

12.3.3.3 R-ACK3

R-ACK3 is reserved for future initialization options. It is a single sinusoid at $f_{R\text{-}ACK3}$ = 60.375 kHz defined by

$$X_k = \begin{cases} 0, k \neq 14, 0 \leq k \leq 32 \\ A_{R-ACK3}, k = 14 \end{cases}$$

The level and duration of R-ACK3 shall be the same as those of R-ACK1.

12.4 Transceiver training - ATU-C

This subclause and 12.5 define the signals transmitted during transceiver training by the ATU-C and ATU-R, respectively. Synchronization of the mutual training begins with the transmission of R-REVERB1 (see 12.5.2), and is maintained throughout training by both transceivers counting the number of symbols from that point on. Thus C-REVEILLE always coincides with R-QUIET2, C-QUIET5 or C-PILOT3 coincides with R-ECT, and so on.

ATU-C

C-REVEILLE	**C-QUIET3 or C-PILOT1**	**C-REVERB1**	**C-QUIET4 or C-PILOT2**	**C-ECT**	**C-REVERB2**	**C-QUIET5 or C-PILOT3**	**C-REVERB3**

ATU-R

R-QUIET2	**R-REVERB1**	**R-QUIET3 or R-PILOT 1**	**R-ECT**	**R-REVERB2**

time →

Figure 31 – Timing diagram of transceiver training (12.4-12.5)

12.4.1 C-REVEILLE

C-REVEILLE is a single frequency sinusoid at $f_{C\text{-}REVEILLE}$ = 241.5 kHz. Referring to figure 2, C-REVEILLE is defined by

$$X_k = \begin{cases} 0, k \neq 56, 0 \leq k \leq 256 \\ A_{C-REVEILLE}, k = 56 \end{cases}$$

where $A_{C\text{-}REVEILLE}$ shall be such that the transmit power level is −4 dBm for the first 64 symbols, and −28 dBm for the second 64 symbols. C-REVEILLE shall be used as an acknowledgment of the detection of R-ACK and as a transition to C-QUIET3 or C-PILOT1; it shall be transmitted for 128 consecutive symbols without cyclic prefix.

If the R-ACK1 was detected earlier the ATU-C shall enter C-QUIET3; if R-ACK2 was detected it shall enter C-PILOT1

12.4.2 C-QUIET3

During C-QUIET3, or C-PILOT1 as appropriate, the ATU-C shall measure the aggregate received upstream power on sub-carriers 7–18 of R-REVERB1, and thereby calculate a downstream PSD.

Upon detection of the first symbol of R-REVERB1 the ATU-C shall start a timer: this establishes synchronization of the subsequent transitions between states at ATU-C and ATU-R. After 512 symbols the ATU-C shall go to C-REVERB1. Thus the minimum duration of C-QUIET3 is 512 symbols, but it will exceed this by the round-trip propagation and signal-processing time plus the amount of time required by ATU-R to detect C-QUIET3 and respond by transmitting R-REVERB1 (see 12.5.2).

C-REVERB1 follows C-QUIET3.

12.4.3 C-PILOT1

C-PILOT1 is a single frequency sinusoid at $f_{C\text{-}PILOT1}$ = 276 kHz, defined by

$$X_k = \begin{cases} 0, k \neq 64, 0 \leq k \leq 256 \\ A_{C-PILOT1}, k = 64 \end{cases}$$

where $A_{C\text{-}PILOT1}$ shall be such that the transmit power level is −4 dBm.

The duration of C-PILOT1 shall be defined in the same way as that of C-QUIET3. C-REVERB1 follows C-PILOT1.

12.4.4 C-REVERB1

C-REVERB1 is a signal that allows the ATU-R receiver to adjust its automatic gain control (AGC) to an appropriate level. The data pattern used in C-REVERB1 shall be the pseudo-random downstream sequence (PRD), d_n for n = 1 to 512, defined in 6.9.3 and repeated here for convenience:

$d_n = 1$	for n = 1 to 9
$d_n = d_{n-4} \oplus d_{n-9}$	for n = 10 to 512

The bits shall be used as follows: the first pair of bits (d_1 and d_2) is used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); then the first and second bits of subsequent pairs are used to define the X_i and Y_i for i = 1 to 255 as follows:

d_{2i+1}, d_{2i+2}	X_i, Y_i
0 0	+ +

0	1	+	−
1	0	−	+
1	1	−	−

NOTES

1 The period of PRD is only 511 bits, so $d_{512} = d_1$

2 The d_1 to d_9 are re-initialized for each symbol, so each symbol of C-REVERB1 uses the same data

Bits 129 and 130, which modulate the pilot carrier ($i = 64$), shall be overwritten by {0,0}: generating the {+,+} constellation.

The nominal transmit PSD for C-REVERB1 is −40 dBm/Hz. If, however, the total upstream power measured on sub-carriers 7–18 is greater than 3 dBm, then the PSD for C-REVERB1 and all subsequent downstream signals shall be as follows:

Upstream received power	< 3	4	5	6	7	8	9	dBm
Max downstream PSD	−40	−42	−44	−46	−48	−50	−52	dBm/Hz

This chosen level shall become the reference level for all subsequent gain calculations.

The duration of C-REVERB1 is 512 (repeating) symbols without cyclic prefix. If the R-ACK1 was detected earlier the ATU-C shall then enter C-QUIET4; if R-ACK2 was detected it shall enter C-PILOT2.

12.4.5 C-QUIET4

The duration of C-QUIET4 is 3072 symbols. C-ECT follows C-QUIET4.

12.4.6 C-PILOT2

The C-PILOT2 signal is the same as C-PILOT1; the duration is 3072 symbols.

12.4.7 C-ECT

C-ECT is a vendor-defined signal that is used to train the echo canceller at ATU-C for EC implementations. Vendors of FDM versions have complete freedom to define their C-ECT signal. The duration of C-ECT, however, is fixed at 512 symbols. The receiver at ATU-R should ignore this signal. C-REVERB2 follows C-ECT.

NOTE - The level of the ADSL signal in the frequency band from 0 to about 10 kHz that leaks through the POTS low-pass filter is tightly limited (see 10.4). Therefore it is recommended that sub-carriers 1–4 not be used for C-ECT, or, at least, that they be transmitted at a much lower level.

12.4.8 C-REVERB2

C-REVERB2 is a signal that allows the ATU-R receiver to perform synchronization and to train any receiver equalizer. C-REVERB2 is the same as C-REVERB1 (see 12.4.3). The duration of C-REVERB2 is 1536 (repeating) symbols without cyclic prefix. If the R-ACK1 was detected earlier the ATU-C shall enter C-QUIET5; if R-ACK2 was detected it shall enter C-PILOT3

12.4.9 C-QUIET5

The duration of C-QUIET5 is 512 symbols. C-REVERB3 follows C-QUIET5.

12.4.10 C-PILOT3

C-PILOT3 is the same as C-PILOT1 (12.4.3).

12.4.11 C-REVERB3

C-REVERB3 is a second training signal, which allows the ATU-R receiver to perform or maintain synchronization and to further train any receiver equalizer. C-REVERB3 is the same as C-REVERB2 (see 12.4.6). The duration of C-REVERB3 is 1024 (repeating) symbols without cyclic prefix. This is the last segment of transceiver training. C-SEGUE1 follows immediately.

12.5 Transceiver training – ATU-R

12.5.1 R-QUIET2

The minimum duration of R-QUIET2 is 128 DMT symbols. The ATU-R shall progress to R-REVERB1 only after it has detected the whole of C-REVEILLE and any part of the following C-QUIET3 or C-PILOT1 that is needed for reliable detection. The time for detection of these signals shall not exceed 128 symbols each. If the ATU-R does not detect both signals within 128 symbols each it shall reset to R-ACT-REQ.

12.5.2 R-REVERB1

R-REVERB1 is used to allow the ATU-C to

- measure the upstream wideband power in order to adjust the ATU-C transmit power level;
- adjust its receiver gain control;
- synchronize its receiver and train its equalizer.

The data pattern used in R-REVERB1 shall be the pseudo-random upstream sequence PRU defined in 7.9.3 and repeated here for convenience:

$$d_n = 1 \quad \text{for } n = 1 \text{ to } 6$$
$$d_n = d_{n-5} \oplus d_{n-6} \quad \text{for } n = 7 \text{ to } 64$$

The bits are used as follows: the first pair of bits (d_1 and d_2) is used for the dc and Nyquist sub-carriers (the power assigned to them is, of course, zero, so the bits are effectively ignored); then the first and second bits of subsequent pairs are used to define the X_i and Y_i for i = 1 to 31 as defined for C-REVERB1 in 12.4.4.

NOTES

1 The period of PRD is only 63 bits, so $d_{64} = d_1$

2 The d_1 to d_6 are re-initialized for each symbol, so each symbol of R-REVERB1 uses the same data .

Bits 33 and 34, which modulate the pilot carrier (i = 16), shall be overwritten by {0,0}: generating the (+ +) constellation.

The nominal transmit PSD for R-REVERB1 and all subsequent upstream signals is –38 dBm/Hz.

R-REVERB1 is a periodic signal, without cyclic prefix, that is transmitted consecutively for 4096 symbols. The first 512 symbols coincide with C-QUIET3 or C-PILOT1 signal in time, the second 512 symbols coincide with C-REVERB1, and the last 3072 symbols coincide with C-QUIET4 or C-PILOT2.

If C-ACT1 or C-ACT2 was detected earlier the ATU-R shall enter R-QUIET3 immediately after R-REVERB1; if C-ACT3 or C-ACT4 was detected the ATU-R may enter R-PILOT1 or R-QUIET3 at the vendor's discretion.

12.5.3 R-QUIET3

The duration of R-QUIET3 is nominally 2048 symbols, of which the first 512 symbols coincide with C-ECT in time, and the next 1536 symbols coincide with C-REVERB2. The final symbol of R-QUIET3 may be shortened by any number of samples that is an integer multiple of four in order to accommodate transmitter to receiver frame alignment. R-ECT immediately follows R-QUIET3.

12.5.4 R-PILOT1

R-PILOT1 is a single frequency sinusoid at $f_{\text{R-PILOT1}} = 69$ kHz, defined by

$$X_k = \begin{cases} 0, k \neq 16, 0 \leq k \leq 256 \\ A_{\text{R-PILOT1}}, k = 16 \end{cases}$$

where $A_{\text{R-PILOT1}}$ shall be such that the transmit power level is −2 dBm.

The nominal duration of R-PILOT1 is the same as that of R-QUIET3, but it may be shortened by any number of samples that is an integer multiple of four in order to accommodate transmitter to receiver frame alignment. R-ECT immediately follows R-PILOT1.

12.5.5 R-ECT

R-ECT, similar to C-ECT, is a vendor-defined signal that may be used to train an echo canceller at ATU-R. Vendors of FDM versions have absolute freedom to define the R-ECT signal. The duration of R-ECT, however, is fixed at 512 DMT symbols. The receiver at ATU-C should ignore this signal. R-REVERB2 follows R-ECT.

NOTE - The level of the ADSL signal in the frequency band from 0 to about 10 kHz that leaks through the POTS low-pass filter is tightly limited (see 10.4). Therefore it is recommended that sub-carriers 1–4 not be used for R-ECT, or, at least, that they be transmitted at a much lower level.

12.5.6 R-REVERB2

The signal R-REVERB2 is the same as R-REVERB1 (see 12.5.2); it can be used by ATU-C to perform timing recovery and receiver equalizer training.

NOTE - Some implementations of ATU-R transmitters may change the symbol timing between R-REVERB1 and R-REVERB2 (see 12.5.3 and 12.5.4); this would require a corresponding shift of any receiver timing acquired during R-REVERB1.

The duration of R-REVERB2 is 1024 symbols. This signal is the last segment of transceiver training. ATU-R then begins channel analysis, and starts transmitting R-SEGUE1.

ATU-C

C-SEGUE1	C-RATES1 , C-CRC1 , C-MSGS1, and C-CRC2	C-MEDLEY	C-REVERB4

ATU-R

R-SEGUE1	R-REVERB3	R-SEGUE2	R-RATES1, R-CRC1, R-MSGS1, and R-CRC2	R-MEDLEY	R-REVERB4

time →

Figure 32 – Timing diagram of channel analysis (12.6-12.7)

12.6 Channel analysis (ATU-C)

During channel analysis the synchronization between ATU-C and ATU-R may be broken during R-REVERB3, which has an indefinite duration; this potential timeout is described in 12.7.2. Furthermore, if during channel analysis any CRC check sum indicates an error in any of the control data, this shall trigger a reset to C-QUIET1.

12.6.1 C-SEGUE1

Except for the pilot tone, C-SEGUE1 is generated from a tone-by-tone 180 degree phase reversal of C-REVERB1 (i.e. + maps to –, and – maps to +, for each of the 4-QAM signal constellation). The duration of C-SEGUE1 is 10 (repeating) symbol periods. Following C-SEGUE1, ATU-C enters state C-RATES1.

12.6.2 C-RATES1

C-RATES1 is the first ATU-C signal for which a cyclic prefix (defined in 6.10) is used. The purpose of C-RATES1 is to transmit four options for data rates and formats to the ATU-R. Each option consists of three fields:

– B_F lists the number of bytes in the fast buffer for each of AS0, AS1, AS2, AS3, LS0, LS1, LS2, LS0 (upstream), LS1 (upstream), LS2 (upstream) channels, in that order; B_F has a total of 80 (= 10 ¥ 8) bits. The first 8 bits of B_F specify the number of bytes in AS0, the second 8 bits specify the number of bytes in AS1, and so on. Each byte of B_F is transmitted with least significant bit first;

– B_I similarly lists the number of bytes in the interleaved buffer;

– {R_F, R_I, S, I, FS(LS2)} is a ten-byte quantity comprising

– R_F , the number of parity bytes per symbol in the fast buffer (downstream);
– R_I, the number of parity bytes per symbol in the interleave buffer (downstream);
– S, the number of symbols per codeword (downstream);
– I, the interleave depth (downstream) in codewords for the interleave buffer;
– FS(LS2), the frame size (in bytes) of the bearer service transported in the LS2 channel;
– the same five quantities {R_F, R_I, S, I, FS(LS2)} in the upstream direction (one-byte each, in that order).

The four options are transmitted in order of decreasing preference. C-RATES1 is preceded by a 4-byte prefix of [01010101 01010101 01010101 01010101]. Figure 33 summarizes C-RATES1 and R-RATES1 (see 12.7.4).

C-RATES1	Prefix	Option 1			Option 2			Option 3			Option 4		
		B_F	B_I	*RRSI*	B_F	B_I	*RRSI*	B_F	B_I	*RRSI*	B_F	B_I	*RRSI*
Number of bytes	4	10	10	10	10	10	10	10	10	10	10	10	10

R-RATES1	Prefix	Option 1			Option 2			Option 3			Option 4		
		B_F	B_I	*RRSI*	B_F	B_I	*RRSI*	B_F	B_I	*RRSI*	B_F	B_I	*RRSI*
Number of bytes	4	3	3	5	3	3	5	3	3	5	3	3	5

Figure 33 – C-RATES1 and R-RATES1 (12.6.2 and 12.7.4)

Only one bit of information is transmitted in each symbol of C-RATES1: a zero bit is encoded to one symbol of C-REVERB1 and a one bit is encoded to one symbol of C-SEGUE1. Since there are a total of 992 bits of C-RATES1 information, the duration of C-RATES1 is 992 symbols. The 992 bits are to be transmitted in the order shown in figure 33, with the least significant bit first. That is, the least significant bit of option 1, B_F, is to be transmitted during the 33rd symbol of C-RATES1, after the prefix. Following C-RATES1, the ATU-C shall enter state C-CRC1.

12.6.3 C-CRC1

C-CRC1 is a cyclic redundancy code for detection of errors in the reception of C-RATES1 at the ATU-R. The CRC bits are computed from the C-RATES1 bits using the equation:

$$c(D) = a(D)\, D^{16} \text{ modulo } g(D),$$

where

$$a(D) = a_0 D^{959} \oplus a_1 D^{958} \ldots \oplus a_{959}$$

is the message polynomial formed from the 960 bits of C-RATES1, with a_0 the least significant bit of the first byte of C-RATES1 (i.e., option 1 B_F);

$$g(D) = D^{16} \oplus D^{12} \oplus D^5 \oplus 1$$

is the CRC generator polynomial, and

$$c(D) = c_0 D^{15} \oplus c_1 D^{14} \ldots\ldots \oplus c_{14} D \oplus c_{15}$$

is the CRC check polynomial.

The 16 bits $c_0 - c_{15}$ are transmitted (c_0 first and c_{15} last) in 16 symbol periods using the method described in 12.6.2. Following C-CRC1, the ATU-C shall enter state C-MSGS1.

12.6.4 C-MSGS1

C-MSGS1 transmits a 48-bit message signal to the ATU-R. This message includes vendor identification, ATU-C transmit power level used, trellis code option, echo canceller option, etc. The message, *m*, is defined by:

$$m = \{m_{47}, m_{30}, \ldots\ldots m_1, m_0\}$$

with m_0 being transmitted first. The message components are defined in the following sub-clauses, and their assigned positions within the composite message, *m*, are defined in table 36.

A total of 48 symbol periods are used to communicate the 48-bit message, using the encoding method described in 12.6.2. Following C-MSGS1, the ATU-C shall enter state C-CRC2.

Table 36 - Assignment of 48 bits of C-MSGS1

Suffix(ces) of m_i	Parameter
47–44	reserved for future use
43–28	vendor identification
27,26	reserved for future use
25–18	version number
17	constellation coding option
16	echo canceling option
15,14	reserved for future use
13,12	maximum possible transmit PSD
11,10,9	reserved for future use
8,7,6	transmit PSD during initialization
5,4	reserved for future use
3–0	maximum numbers of bits per sub-carrier supported

NOTES
1 All bits "reserved for future use" shall be set to 0 until defined.
2 Within the separate fields the least significant bits have the lowest subscripts.

12.6.4.1 Vendor identification - Bits 43–28

The vendor ID is binarily coded. Thirty-seven codes have so far been assigned; they are defined in Annex D. Bits 47–44, the most significant bits (MSBs), may be used to identify more vendors in the future.

12.6.4.2 Version number - Bits 25–18

To facilitate upgrades in the future, six bits are reserved to allow any vendor to include a version number for each unit. When an ATU-C connects to an ATU-R with the same vendor ID, this may serve to simplify upgrades, diagnostics, maintenance, etc.

12.6.4.3 Constellation coding option - Bit 17

$m_{17} = 0$ shall indicate no trellis coding capability, $m_{17} = 1$ shall indicate trellis coding capability.

12.6.4.4 Echo cancellation option - Bit 16

$m_{16} = 0$ shall indicate no echo cancellation, $m_{16} = 1$ shall indicate echo cancellation.

12.6.4.5 Maximum possible transmit PSD – Bits 13,12

As defined in 6.13.3, the ATU-C may transmit, under some circumstances and in some frequency bands, at a PSD as high as –34 dBm/Hz. The ability to do this shall be signaled to the ATU-R so that it may calculate the optimum loading. The coding rules for m_{13}, m_{12} are

m_{13} m_{12}	Max. PSD dBm/Hz
1 1	–34
1 0	–36
0 1	–38
0 0	–40

12.6.4.6 Transmit PSD during initialization – Bits 8,7,6

The ATU-C shall report the level of C-REVERB1 chosen as a result of the calculation described in 12.4.3. The encoding rules for m_8, m_7, m_6 are

m_8	m_7	m_6	PSD dBm/Hz
1	1	1	–40
1	1	0	–42
1	0	1	–44
1	0	0	–46
0	1	1	–48
0	1	0	–50
0	0	1	–52

12.6.4.7 Maximum numbers of bits per sub-carrier supported - Bits 3–0

The $N_{downmax}$ (transmit) capability shall be encoded onto $\{m_3 - m_0\}$ with a conventional binary representation (e.g., 1101 = 13)

The maximum number of bits for the upstream data, N_{upmax}, that the ATU-C receiver can support need not be signaled to the ATU-R; it will be implicit in the bits and gains message, C-B&G, which is transmitted after channel analysis.

12.6.5 C-CRC2

C-CRC2 is a cyclic redundancy code for detection of errors in the reception of C-MSGS1 at the ATU-R. The CRC polynomial is generated in the same way as defined in 12.6.3. These 16 bits shall be transmitted in 16 symbol periods using the method described in 12.6.2. Following C-CRC2, the ATU-C shall enter state C-MEDLEY.

12.6.6 C-MEDLEY

C-MEDLEY is a wideband pseudo-random signal used for estimation at the ATU-R of the downstream SNR. The data to be transmitted shall be derived from the pseudo-random sequence, PRD, and modulated as defined in 6.9.3 and 12.4.4. In contrast to C-REVERB1, however, the data sequence continues from one symbol to the next (i.e., d_1 to d_9 are not re-initialized for each symbol); since PRD is of length 511, and 512 bits are used for each symbol, the sub-carrier vector for C-MEDLEY therefore changes from one symbol period to the next. The pilot sub-carrier is over-written by the (+,+) signal constellation.

C-MEDLEY shall be transmitted for 16384 symbol periods. Following C-MEDLEY the ATU-C shall enter the state C-REVERB4.

12.6.7 C-REVERB4

C-REVERB4 is similar to C-REVERB2 (see 12.4.6), the only difference being the addition of a cyclic prefix on every symbol. C-REVERB4 continues into the exchange procedure, and its duration is not fixed. The timeout features of C-REVERB4 are defined in 12.8.1

12.7 Channel analysis (ATU-R)

During channel analysis there are two situations where the ATU-R will reset itself to R-ACT-REQ: a timeout and a detected error in the received control data. A timeout occurs if the time in R-REVERB3 exceeds the limit of 4000 symbols. Also, if any C-CRC checksum indicates there is an error in the received control data, then it shall trigger a reset to R-ACT-REQ.

12.7.1 R-SEGUE1

Except for the pilot tone, R-SEGUE1 is generated from a tone-by-tone 180 degree phase reversal of R-REVERB1 (i.e. + maps to –, and – maps to +, for each of the 4-QAM signal constellation). The duration of R-SEGUE1 is 10 symbol periods. Following R-SEGUE1 the ATU-R shall enter state R-REVERB3.

12.7.2 R-REVERB3

R-REVERB3 is similar to R-REVERB1 (see 12.5.2); the only difference is the addition of a cyclic prefix to every symbol. The duration of R-REVERB3 is not fixed but has a maximum of 4000 symbols. If C-SEGUE1 is not detected within 4000 symbols the ATU-R shall timeout and reset to R-ACT-REQ. After detection of C-SEGUE1 through C-CRC2, the ATU-R shall continue to send R-REVERB3 for 20 additional symbols before entering R-SEGUE2.

12.7.3 R-SEGUE2

The signal R-SEGUE2 is the same as R-SEGUE1 (see 12.7.1). The duration of R-SEGUE2 is 10 symbol periods. Following R-SEGUE2 the ATU-R shall enter state R-RATES1.

12.7.4 R-RATES1

The purpose of R-RATES1 for the upstream channel is the same as that of C-RATES1 for the downstream channel (see 12.6.2). Each option consists of three fields:

- B_F lists the number of bytes in the fast buffer for each of LS0, LS1, LS2, in that order; B_F has a total of 24 (= 3 ¥ 8) bits. The first 8 bits of B_F specify the number of bytes in LS0, the second 8 bits specify the number of bytes in LS1, and so on. Each byte of B_F is transmitted with least significant bit first;

- B_I similarly lists the number of bytes in the interleaved buffer;

- {R_F, R_I, S, I, FS(LS2)} is a five-byte quantity comprising
  - R_F , the number of parity bytes per symbol in the fast buffer (upstream);
  - R_I, the number of parity bytes per symbol in the interleave buffer (upstream);
  - S, the number of symbols per codeword (upstream);
  - I, the interleave depth (upstream) in codewords for the interleave buffer;
  - FS(LS2), the frame size (in bytes) of the bearer service transported in the LS2 channel.

The four options are transmitted in order of decreasing preference. Figure 33 defines R-RATES1 as well as C-RATES1. For the present issue of the standard, ATU-C has control over all the data rates, so R-RATES1 is copied from the appropriate fields of C-RATES1.

Only one bit of information shall be transmitted during each symbol period of R-RATES1: a zero bit is encoded to one symbol of R-REVERB1 and an one bit is encoded to one symbol of R-SEGUE1. Since there are a total of 384 bits of RATES1 information, the length of R-RATES1 is 384 symbols. The 384 bits are to be transmitted in the order shown in figure 33, with the least significant bit first. That is, the least significant bit of option 1, B_F (see table 32), is to be transmitted during the 33rd symbol of R-RATES1, after the prefix. Following R-RATES1, the ATU-R shall enter state R-CRC1.

12.7.5 R-CRC1

R-CRC1 is a cyclic redundancy code intended for detection of an error in the reception of R-RATES1 at the ATU-C. The CRC polynomial c(D) and generator polynomial g(D) are the same as for C-CRC1 (see 12.6.3). The 16 bits c_0 to c_{15} are transmitted (c_0 first and c_{15} last) in 16 symbol periods using the same method as R-RATES1 (see 12.7.4). Following R-CRC1, the ATU-R shall enter state R-MSGS1.

12.7.6 R-MSGS1

R-MSGS1 transmits a 48-bit message signal to the ATU-C. This message includes vendor identification, trellis code option, echo canceller option, etc. The message, m, is defined by:

$$m = \{m_{47}, m_{30}, \ldots\ldots, m_1, m_0\}$$

with m_0, the least significant bit, being transmitted first. The message components are defined in the following sub-clauses, and their assigned positions within the composite message, m, are defined in table 37.

A total of 48 symbol periods shall be used to communicate the 48 bit message, using the encoding method described in 12.6.2 Following R-MSGS1, the ATU-R shall enter state R-CRC2.

Table 37 - Assignment of 48 bits of R-MSGS1

Suffix(ces) of m_i	Parameter
47–44	Reserved for future use
43–28	Vendor Identification
27,26	Reserved for future use
25–18	Version Number
17	Constellation coding option
16	Echo cancelling option
15–4	Reserved for future use
3–0	Maximum numbers of bits per sub-carrier supported

NOTES
1 All bits "reserved for future use" shall be set to 0 until defined.
2 Within the separate fields the least significant bits have the lowest subscripts.

12.7.6.1 Vendor identification – Bits 43–28

The vendor ID is coded in binary as defined in 12.6.4.1

12.7.6.2 Version number – Bits 25–18

The version number is encoded as defined in 12.6.4.2

12.7.6.3 Trellis coding option – Bit 17

m_{17} = 0 shall indicate no trellis coding capability; m_{17} = shall 1 indicate trellis coding capability.

12.7.6.4 Echo cancellation option – Bit 16

m_{16} = 0 shall indicate no echo cancellation; m_{16} = 1 shall indicate echo cancellation.

12.7.6.5 Maximum numbers of bits per sub-carrier supported – Bits 3–0

The N_{upmax} (transmit) capability shall be encoded onto $\{m_3 - m_0\}$ with a conventional binary representation (e.g., 1101 = 13)

NOTE - The maximum number of bits for the downstream data, $N_{downmax}$, that the ATU-R receiver can support need not be signaled to the ATU-C; it will be implicit in the bits and gains message, R-B&G, which is transmitted after channel analysis.

12.7.7 R-CRC2

R-CRC2 is a cyclic redundancy code for detection of errors in the reception of R-MSGS1 at the ATU-C. The CRC polynomial is generated in exactly the same way as described in 12.6.3. These 16 bits are transmitted in 16 symbol periods using the method described in 12.7.4. Following R-CRC2, the ATU-R shall enter state R-MEDLEY.

12.7.8 R-MEDLEY

R-MEDLEY is a wideband pseudo-random signal used for estimation of the upstream SNR at the ATU-C. The data to be transmitted are derived from the pseudo-random sequence PRU defined in 12.5.2, continuing from one symbol to the next. Because the sequence is of length 63, and 64 bits are used for each symbol, the sub-carrier vector for R-MEDLEY changes from one symbol period to the next. The pilot sub-carrier is over-written by the (+,+) signal constellation. R-MEDLEY is transmitted for 16384 symbol periods. Following R-MEDLEY the ATU-R shall enter state R-REVERB4.

12.7.9 R-REVERB4

R-REVERB4 is the same as R-REVERB3 (see 12.7.2). The duration of R-REVERB4 is 128 symbols. This signal marks the end of channel analysis, and R-SEGUE3 immediately follows R-REVERB4.

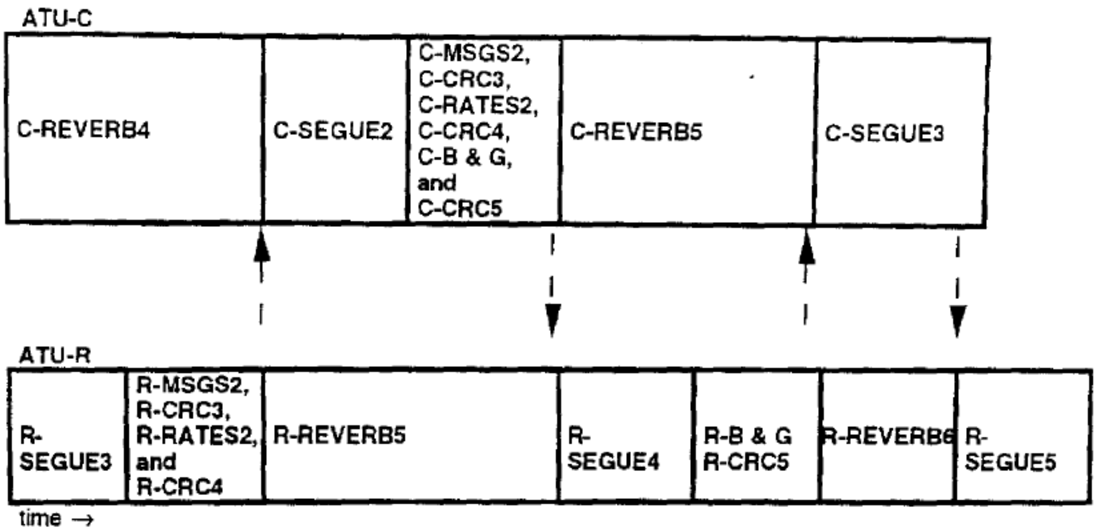


Figure 34 — Timing diagram of exchange (12.8-12.9)

12.8 Exchange (ATU-C)

During exchange there are two events that shall cause the ATU-C to reset to C-QUIET1: timeouts and error detection by a CRC checksum. The exchange procedure is partly synchronized between ATU-C and ATU-R, and partly interactive. During the interactive part (C-REVERB4 and C-REVERB5) a timeout shall occur when the time in that state exceeds 4000 symbols.

12.8.1 C-REVERB4

If the ATU-C does not detect R-SEGUE3 within 4000 symbols, it shall timeout and reset to C-QUIET1. After detection of R-SEGUE3 and R-MSGS2, R-CRC3, R-RATES2, and R-CRC4, the ATU-C shall continue to transmit C-REVERB4 for another 80 symbols before progressing to state C-SEGUE2 (see 12.8.2).

12.8.2 C-SEGUE2

The signal C-SEGUE2 is the same as C-SEGUE1 (see 12.6.1). The duration of C-SEGUE2 is 10 symbol periods. Following C-SEGUE2 the ATU-C shall enter state C-MSGS2.

12.8.3 C-MSGS2

C-MSGS2 transmits a 32-bit message signal to the ATU-R. This message includes the total number of bits per symbol supported, the estimated upstream loop attenuation, and the performance margin with the selected rate option. The message, m, is defined by:

$$m = \{m_{31}, m_{30}, \ldots\ldots m_1, m_0\}$$

with m_0 being transmitted first. The message components are defined in the following sub-clauses, and their assigned positions within the composite message, m, are defined in table 38

Table 38 - Assignment of 32 bits of C-MSGS2

Suffix(ces) of m_i	Parameter

31–26	Estimated average loop attenuation
25–21	Reserved for future use
20–16	Performance margin with selected rate option
15–9	Reserved for future use
8–0	Total number of bits supported
NOTES 1 All bits "reserved for future use" shall be set to 0 until defined. 2 Within the separate fields the least significant bits have the lowest subscripts.	

A total of 4 symbol periods shall be used to communicate the 32 bit message, with 8 bits transmitted on each symbol. Two bits are encoded onto each of the sub-carriers numbered 43 through 46 using the 4QAM constellation labeling given in 6.9.3 (for the synchronization symbol) and 12.4.3 (for C-REVERB1). The same two bits are also encoded in the same way onto a set of backup carriers, namely, sub-carriers 37 through 40. The least significant byte of the message is transmitted in the first symbol of C-MSGS2, with the two least significant bits of each byte encoded onto carriers 43 and 37. In addition, the pilot, sub-carrier 64, shall be modulated with (+,+). Following C-MSGS2, the ATU-C shall enter state C-CRC3.

12.8.3.1 Estimated average upstream loop attenuation

During channel analysis the ATU-C estimates the upstream channel gain in preparation for computing the SNR for each tone; it shall also calculate the average loop attenuation. This attenuation, rounded to the nearest 0.5 dB, is then encoded into bits 31–26 of C-MSGS2 as the integer binary representation of twice the attenuation (e.g., if the average attenuation is 16.5 dB then $\{m_{31}-m_{26}\}$ = 100001).

12.8.3.2 Performance margin with selected rate option

The ATU-C receiver shall calculate the performance margin for each of the rates options sent from the ATU-R during R-RATES1, and then select one of the options with a satisfactory margin. This margin (rounded to the nearest dB) is encoded into bits 20–16 of C-MSGS2 using a conventional binary representation (e.g., if the margin is 9 dB then $\{m_{20}-m_{16}\}$ = 01001).

12.8.3.3 Total number of bits per symbol supported

The ATU-C receiver shall also calculate the maximum number of bits per symbol that the upstream channel can support with a performance margin of 6 dB at an error rate of 10^{-7}. This number is encoded into bits 8–0 using a conventional binary representation (e.g., if the maximum number of bits that can be supported is 127 (data rate = 508 kbit/s), $\{m_8-m_0\}$ = 001111111).

12.8.4 C-CRC3

C-CRC3 is a cyclic redundancy code for detection of errors in the reception of C-MSGS2 at the ATU-R. The CRC polynomial c(D) and generator polynomial g(D) are the same as for CRC1, as defined in 12.6.3. These bits are transmitted in 2 symbol periods using the method described in 12.8.3. Following C-CRC3, the ATU-C shall enter state C-RATES2.

12.8.5 C-RATES2

C-RATES2 is the reply to R-RATES1 (see 12.7.4). It combines the downstream rate information contained in R-RATES2 (in the form of one selected option) with the option number of the highest upstream data rate that can be supported based on the measured SNR of the upstream channel. It thus transmits the final decision on the rates that will be used in both directions. The length of C-RATES2 is equal to 8 bits, and the bit pattern for C-RATES2 is shown in table 39. Other bit patterns that are not specified in the table are reserved for future use. If none of the options requested during C-RATES1 and R-RATES1 can be implemented, ATU-C shall transmit the all-options-fail code defined in table 39, and then return to C-QUIET1 for retraining. One symbol

period is used to transmit these 8 bits using the method described in 12.8.3. Following C-RATES2, the ATU-C shall enter state C-CRC4.

Table 39 – Bit pattern for C-RATES2

(Downstream, upstream)	Bit pattern for C-RATES2 (MSB first) (note 1)
(option 1, option 1)	00010001
(option 1, option 2)	00010010
(option 1, option 3)	00010100
(option 1, option 4)	00011000
(option 2, option 1)	00100001
(option 2, option 2)	00100010
(option 2, option 3)	00100100
(option 2, option 4)	00101000
(option 3, option 1)	01000001
(option 3, option 2)	01000010
(option 3, option 3)	01000100
(option 3, option 4)	01001000
(option 4, option 1)	10000001
(option 4, option 2)	10000010
(option 4, option 3)	10000100
(option 4, option 4)	10001000
all options fail (Note 2)	00000000

NOTES
1 All other bit patterns that are not shown are reserved for future use.
2 If it is determined that none of the four options can be implemented with the connection the ATU-C shall return to C-QUIET1 for retraining.

12.8.6 C-CRC4

C-CRC4 is a cyclic redundancy code for detection of errors in the reception of C-RATES2 at the ATU-R. Its relation to C-RATES2 is the same as that of C-CRC3 to C-MSGS2. Following C-CRC4, the ATU-C shall enter state C-B&G.

12.8.7 C-B&G

C-B&G shall be used to transmit to the ATU-R the bits and gains , $\{b_1, g_1, b_2, g_2, \ldots b_{31}, g_{31}\}$, that are to be used on the upstream carriers. b_i indicates the number of bits to be coded by the ATU-R transmitter onto the i th upstream carrier; g_i indicates the scale factor, relative to the gain that was used for that carrier during the transmission of R-MEDLEY, that shall be applied to the i th upstream carrier. Because no bits or energy will be transmitted at dc or one-half the sampling rate, b_0, g_0, b_{32}, and g_{32} are all presumed to be zero and shall not transmitted.

Each b_i shall be represented as an unsigned 4-bit integer, with valid b_is lying in the range of zero to N_{upmax}, the maximum number of bits that the ATU-R is prepared to modulate onto any sub-carrier, which is communicated in R-MSGS1.

Each g_i shall be represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 01000000 0000 would instruct the ATU-R to scale the constellation for carrier i, by a gain factor of 2, so that the power in that carrier shall be 6 dB higher than it was during R-MEDLEY.

For sub-carriers where no data are transmitted and the receiver will never allocate bits (e.g., out-of-band channels), both b_i and g_i shall be set to zero (0000 and 00000000 000, respectively). For sub-carriers where no data are currently to be transmitted, but the receiver may allocate bits later (e.g., as a result of an SNR improvement), the b_i shall be set to zero (0000) and the g_i to 1 (00100000 0000).

A total of 62 bytes of bits and gains information is to be transmitted during C-B&G, and a total of 62 symbol periods is required, using the method described in 12.8.2. Following C-B&G the ATU-C enters state C-CRC5.

12.8.8 C-CRC5

C-CRC5 is a cyclic redundancy code for detection of errors in the reception of C-B&G at the ATU-R. Its relation to C-B&G is the same as that of C-CRC3 to C-MSGS2. Following C-CRC5, the ATU-C shall enter state C-REVERB5.

12.8.9 C-REVERB5

C-REVERB5 is the same as C-REVERB4 (see 12.6.7). The duration of C-REVERB5 depends upon the state of the ATU-R and the internal processing of the ATU-C. The ATU-C shall transmit C-REVERB5 until it has received, checked the reliability of, and established the downstream bits and gains information contained in R-B&G. The ATU-C shall enter state C-SEGUE3 as soon as it is prepared to transmit according to the conditions specified in R-B&G.

12.8.10 C-SEGUE3

C-SEGUE3 is used to notify the ATU-R that the ATU-C is about to enter the steady-state state C-SHOWTIME. The signal C-SEGUE3 is the same as C-SEGUE1 (see 12.6.1). The duration of C-SEGUE3 is 10 symbol periods. Following C-SEGUE3 the ATU-C has completed initialization and enters state C-SHOWTIME.

12.9 Exchange – ATU-R

During exchange there are two cases where the ATU-R shall reset itself: timeouts and error detection by a CRC checksum. Both shall trigger a reset to R-ACT-REQ. The exchange procedure is partly synchronized between ATU-C and ATU-R, and partly interactive. During the interactive parts (R-REVERB5 and R-REVERB6) a timeout shall occur when the time in either state exceeds 4000 symbols.

12.9.1 R-SEGUE3

The signal R-SEGUE3 is the same as R-SEGUE1 (see 12.7.1). The duration of R-SEGUE3 is 10 symbol periods. Following R-SEGUE3 the ATU-R shall enter state R-MSGS2.

12.9.2 R-MSGS2

R-MSGS2 transmits a 32-bit message signal to the ATU-C. This message includes the total number of bits per symbol supported, the estimated upstream loop attenuation, and the performance margin with the selected rate option. The message, m, is defined by:

$$m = \{m_{31}, m_{30}, \ldots\ldots m_1, m_0\}$$

with m_0 being transmitted first. The message components are defined in the following sub-clauses, and their assigned positions within the composite message, m, are defined in table 40.

Table 40 - Assignment of 32 bits of R-MSGS2

Suffix(ces) of m_i	Parameter
31–25	Estimated average loop attenuation
24–21	Reserved for future use
20–16	Performance margin with selected rate option
15–12	Reserved for future use
11–0	Total number of bits supported
NOTES 1 All bits "reserved for future use" shall be set to 0 until defined. 2 Within the separate fields the least significant bits have the lowest subscripts.	

A total of 4 symbol periods shall be used to communicate the 32 bit message, with 8 bits transmitted on each symbol. Two bits are encoded onto each of the sub-carriers numbered 6 through 9 using the 4QAM constellation labeling given in 6.9.3 (for the synchronization symbol) and 12.4.3 (for C-REVERB1). The same two bits are also encoded in the same way onto a set of backup carriers, namely, sub-carriers 10 through 13. The least significant byte of the message is transmitted in the first symbol of R-MSGS2, with the two least significant bits of each byte encoded onto carriers 6 and 10. In addition, the pilot, sub-carrier 16, shall be modulated with (+,+). Following R-MSGS2, the ATU-R shall enter state R-CRC3.

12.9.2.1 Estimated average (upstream) loop attenuation

During channel analysis the ATU-R receiver estimates the downstream channel gain in preparation for computing the SNR for each tone; it shall also calculate the average loop attenuation. This attenuation, rounded to the nearest 0.5 dB, is then encoded into bits 31 - 25 of R-MSGS2 as the integer binary representation of twice the attenuation (e.g., if the average attenuation is 21.5 dB then $\{m_{31}, \ldots m_{25}\}$ = 0101011).

12.9.2.2 Performance margin with selected rate option

The ATU-R receiver shall calculate the performance margin for each of the rates options sent from the ATU-C during C-RATES1, and then select one of the options with a satisfactory margin. This margin (rounded to the nearest dB) is encoded into bits 20–16 of R-MSGS2 using a conventional binary representation (e.g., if the margin is 9 dB then $\{m_{20}, \ldots m_{16}\}$ = 01001).

12.9.2.3 Total number of bits per symbol supported

The ATU-R receiver shall also calculate the maximum number of bits per symbol that the downstream channel can support with a performance margin of 6 dB at an error rate of 10^{-7}. This number is encoded into bits 11 - 0 using a conventional binary representation (e.g., if the maximum number of bits that can be supported is 1724 (data rate = 6896 kbit/s), $\{m_{11}, \ldots m_0\}$ = 11010111100).

12.9.3 R-CRC3

R-CRC3 is a cyclic redundancy code for detection of errors in the reception of R-MSGS2 at the ATU-C. The CRC polynomial c(D) and generator polynomial g(D) are as described in 12.6.3. These bits are transmitted in 2 symbol periods using the method described in 12.9.2. Following R-CRC3, the ATU-R shall enter state R-RATES2.

12.9.4 R-RATES2

R-RATES2 is the reply to C-RATES1 based on the results of the downstream channel analysis. Instead of listing the B_F, B_I as in C-RATES1, the ATU-R sends back only the option number of the highest data rate that can be supported based on the measured SNR of the downstream channel. As in C-RATES2, 4 bits are used for the option number. A total of 8 bits are used for R-RATES2, and the bit patterns are shown in table 41. Other bit patterns that are not specified in

the table are reserved for future use. If none of the options requested during C-RATES1 can be implemented, ATU-R then returns to R-ACT-REQ for retraining. One symbol period is used to transmit these 8 bits using the method described in 12.9.2. Following R-RATES2, the ATU-R shall enter state R-CRC4.

Table 41 – Bit pattern for R-RATES2

Downstream	Bit pattern for R-RATES2 (MSB first) (note 1)
option 1	00010001
option 2	00100010
option 3	01000100
option 4	10001000
all options fail (note 2)	00000000
NOTES 1 All other bit patterns that are not shown are reserved for future use. 2 If it is determined that none of the four options can be implemented with the connection, the ATU-R shall return to R-ACT-REQ for retraining.	

12.9.5 R-CRC4

R-CRC4 is a cyclic redundancy code for detection of errors in the reception of R-RATES2 at the ATU-C. Its relation to R-RATES2 is the same as that of R-CRC3 to R-MSGS2. Following R-CRC4, the ATU-R shall enter state R-REVERB5.

12.9.6 R-REVERB5

R-REVERB5 is the same as R-REVERB3 (see 12.7.2). The duration of R-REVERB5 depends upon the state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB5 until it has received and checked the reliability of the upstream bits and gains information contained in C-B&G. After the ATU-R has received C-CRC5, it shall continue to transmit R-REVERB5 for another 64 symbols. It shall then enter R-SEGUE4. If it has not successfully detected all the control signals within 4000 symbols it shall timeout and reset to R-ACT-REQ.

12.9.7 R-SEGUE4

The purpose of R-SEGUE4 is to notify the ATU-C that the ATU-R is about to enter R-B&G. R-SEGUE4 is the same as R-SEGUE3 (see 12.9.1). The duration of R-SEGUE4 is 10 symbol periods. Following R-SEGUE4 the ATU-R enters state R-B&G.

12.9.8 R-B&G

The purpose of R-B&G is to transmit to the ATU-C the bits and gains information, $\{b_1, g_1, b_2, g_2, \ldots\ldots b_{255}, g_{255}\}$, to be used on the downstream sub-carriers. b_i indicates the number of bits to be coded by the ATU-C transmitter onto the i th downstream sub-carrier; g_i indicates the scale factor that shall be applied to the i th downstream sub-carrier, relative to the gain that was used for that carrier during the transmission of C-MEDLEY. Because no bits or energy will be transmitted at DC or one-half the sampling rate, b_0, g_0, b_{256}, and g_{256} are all presumed to be zero, and are not transmitted.

Each b_i is represented as an unsigned 4-bit integer, with valid b_i lying in the range of zero to $N_{downmax}$, the maximum number of bits that the ATU-C is prepared to modulate onto any sub-carrier, which is communicated in C-MSGS1.

Each g_i is represented as an unsigned 12-bit fixed-point quantity, with the binary point assumed just to the right of the third most significant bit. For example, a g_i with binary representation (most significant bit listed first) 0100 0000 0000 would instruct the ATU-C to scale the constellation for carrier i by a gain factor of 2, so that the power in that carrier shall be 6 dB higher than it was during C-MEDLEY.

For sub-carriers where no data are transmitted and the receiver will never allocate bits (e.g., out-of-band channels), both b_i and g_i will be set to zero (0000 and 00000000 000, respectively). For sub-carriers where no data are currently to be transmitted, but the receiver may allocate bits later (e.g., as a result of an SNR improvement), the b_i will be set to zero (0000) and the g_i to 1 (00100000 0000)

A total of 510 bytes of bits and gains information is to be transmitted during R-B&G, so that a total of 510 symbol periods is required. The transmission format is the same as described in 12.9.2. Following R-B&G the ATU-R shall enter state R-CRC5.

12.9.9 R-CRC5

R-CRC5 is a cyclic redundancy code for detection of errors in the reception of R-B&G at the ATU-C. Its relation to R-B&G is the same as that of R-CRC3 to R-MSGS2. Following R-CRC5, the ATU-R shall enter state R-REVERB6.

12.9.10 R-REVERB6

R-REVERB6 is the same as R-REVERB3 (see 12.7.2). The duration of R-REVERB6 depends upon the state of the ATU-C and the internal processing of the ATU-R, but has a maximum of 4000 symbols. The ATU-R shall transmit R-REVERB6 until it has detected all ten symbols ofC-SEGUE3; it shall then enter R-SEGUE5. If it has not successfully detected C-SEGUE3 within 4000 symbols it shall timeout and reset to R-ACT-REQ.

12.9.11 R-SEGUE5

The purpose of R-SEGUE5 is to notify the ATU-C that the ATU-R is about to enter the steady-state state R-SHOWTIME. R-SEGUE5 is identical to R-SEGUE3 (see 12.9.1). The duration of R-SEGUE5 is 10 symbol periods. Following R-SEGUE5 the ATU-R has completed initialization and shall enter state R-SHOWTIME.

13. On-line adaptation and reconfiguration

13.1 The ADSL overhead control (aoc) channel

As stated in 6.2 and 7.2, when any bearer data streams appear in the interleave buffer, then the aoc channel data is carried in the LEX byte, and the "synch" byte shall designate when the LEX byte contains aoc channel data and when it contains a data byte from the bearer data streams. When no bearer data streams are allocated to the interleave data buffer (i.e., all B_I (ASX) = 0 and all B_I (LSX) = 0 for the downstream case or all B_I (LSX) = 0 for the upstream case, respectively), then the "synch" byte carries the aoc channel data directly, because the LEX byte does not exist in the interleave buffer in this case.

13.1.1 aoc message header

The type and length of an aoc message is determined by a byte-length header. In particular, the aoc channel sends all binary zeros in the idle mode, and a valid aoc message always begins with a non-zero byte. Table 42 summarizes the current valid aoc message headers. For example, in the case of a bit swap, the aoc header "11111111" will be detected, and the next byte of aoc data shall determine whether the message is a bit swap request or a bit swap acknowledge (see 13.2). In the case when a standardized function, such as a bit swap, is requested but cannot be performed by either the ATU-C or the ATU-R for whatever the reason, an unable to comply message ("11110000") is issued. Future aoc headers can be added when new aoc messages/functions are identified. Also, a block of aoc header values ("1100xxxx") is set aside for vendor specific aoc messages.

Table 42 - aoc message headers

Value	Interpretation
00000000	Idle mode
00001111	Reconfiguration commands
1100xxxx	Reserved for vendor specific commands
11110000	Unable to comply
11111100	Extended bit swap request
11111111	Bit swap commands

13.1.2 aoc protocol

All aoc messages are transmitted 5 consecutive times for extra security. A transceiver unit shall only act on an aoc message if it has received three identical messages in a time period spanning 5 of that particular message. When a receiving unit detects an unrecognizable command, no action shall be taken by the receiving unit. The transmitting unit (the originating unit of the aoc command) is responsible for any time outs and/or local recovery schemes, when no acknowledgment to its request has been detected over a reasonable period of time. Individual vendors of ADSL transceivers may implement any recovery scheme(s) of their choice.

13.2 High-level on-line adaptation – Bit swapping

Bit swapping enables an ADSL system to change the number of bits assigned to a subcarrier, or change the transmit energy of a subcarrier without interrupting data flow.

Either ATU may initiate a bit swap; the swapping procedures in the upstream and downstream channels are independent, and may take place simultaneously.

13.2.1 Bit swap channel

The bit swap process uses the aoc channel, described in Section 13.1. All bit swap messages shall be repeated five consecutive times over this channel.

13.2.2 Superframe counting

The transceivers coordinate the bit swaps as follows:

– The ATU-C and ATU-R transmitters shall start their counters immediately after transmitting C-SEGUE3 and R-SEGUE5, respectively; this marks the transition between initialization and steady state operation;
– Each transmitter shall increment its counter after sending each ADSL superframe (see 6.2);
– Correspondingly, each receiver shall start its counter immediately after receiving C-SEGUE3 or R-SEGUE5, respectively, and then increment it after receiving each superframe.

Synchronization of the corresponding transmitter and receiver superframe counters is maintained using the synch symbol in the ADSL frame structure. Any form of restart that requires a transition from initialization to steady state shall reset the superframe counter.

13.2.3 Bit swap request

Message header	Message field 1 (16 bits)		Message field 2 (16 bits)		Message field 3 (16 bits)		Message field 4 (16 bits)	
11111111 (8 bits)	Command (8 bits)	Subchannel index (8bits)	Command (8 bits)	Subchannel index (8bits)	Command (8 bits)	Subchannel index (8bits)	Command (8 bits)	Subchannel index (8bits)

Figure 35 — Format of the bit swap request message

The receiver shall initiate a bit swap by sending a bit swap request back to the transmitter via the aoc channel. This request tells the transmitter what subcarriers are to be modified. Figure 35 illustrates the format of the bit swap request message, which contains the following:

– an aoc message header consisting of 8 binary ones;

-- message fields 1–4, each of which each consists of an eight bit command followed by a related eight-bit subchannel index. Valid eight-bit commands for the bit swap message shall be as shown in table 43. The eight-bit subchannel index is counted from low to high frequencies with the lowest frequency subcarrier having the number zero.

Table 43 - Bit swap request commands

Value	Interpretation
00000000	Do nothing
00000001	Increase the allocated number of bits by one.
00000010	Decrease the allocated number of bits by one.
00000011	Change the transmitted power by the factor +1 dB
00000100	Change the transmitted power by the factor +2 dB
00000101	Change the transmitted power by the factor +3 dB
00000110	Change the transmitted power by the factor -1 dB
00000111	Change the transmitted power by the factor -2 dB
00001xxx	Reserved for vendor specific commands

The bit swap request message (i.e., header and message fields) is transmitted five consecutive times.

13.2.4 Extended bit swap request

Because a single-bit sub-carrier is not allowed, an extended bit swap request containing 6 fields shall be used when decreasing the number of bits on a sub-carrier from 2 to 0, or when increasing the number of bits on a sub-carrier from 0 to 2. The format of this extended bit swap request is similar to that of the bit swap request (13.2.3), but the number of message fields is increased to 6, and, as shown in table 44, the message header is 11111100.

Table 44 – Extended bit swap request

Message Header (8 bits)	Message Field #1 (16 bits)		Message Field #2 (16 bits)		Message Field #3 (16 bits)		Message Field #4 (16 bits)		Message Field #5 (16 bits)		Message Field #6 (16 bits)	
11111100												

The extended bit swap request is transmitted 5 consecutive times

13.2.5 Bit swap acknowledge

Message header (8 bits) 11111111	Command (8 bits) 11111111	Bit swap superframe counter number (8 bits)

Figure 36 — Format of the bit swap acknowledge

The transmitter shall act on a bit swap request when it has received three identical bit swap request messages. The transmitter shall then send a bit swap acknowledge. Figure 36 shows the format of the bit swap acknowledge message, which contains the following:

-- an aoc message header containing 8 binary ones;

- one message field that consists of eight binary ones followed by the eight bit superframe counter number, which indicates when the bit swap is to take place. In particular, the new bit and/or transmit energy table(s) shall take effect starting from the first frame (frame 0) of an ADSL superframe, after the specified superframe counter number has been reached. In other words, if the bit swap superframe counter number contained in the bit swap acknowledge message is n, then the new table(s) shall take effect starting from frame 0 of the (n+1)th ADSL superframe.

The bit swap acknowledge is transmitted five consecutive times.

13.2.6 Bit swap – Receiver

The receiver shall act on a bit swap request when it has received three identical bit swap acknowledge messages. The receiver shall then wait until the superframe counter equals the value specified in the bit swap acknowledge. Then, beginning with frame 0 of the next ADSL superframe the receiver shall

– change the bit assignment of the appropriate subcarriers, and perform tone re-ordering based on the new sub-carrier bit assignment;

– update applicable receiver parameters of the appropriate subcarriers to account for a change in their transmitted energy.

13.2.7 Bit swap – Transmitter

After transmitting the bit swap acknowledge, the transmitter shall wait until the superframe counter equals the value specified in the bit swap acknowledge. Then, beginning with frame 0 of the next ADSL superframe, the transmitter shall

– change the bit assignment of the appropriate subcarriers, and perform tone re-ordering based on the new sub-carrier bit assignment;
– change the transmit energy in the appropriate subcarriers by the desired factor.

13.3 Changes to data rates and reconfiguration

Specification of changes to data rates and reconfiguration on demand is for further study.

14. Signaling requirements

ADSL supports both simplex and duplex bearer channels in a variety of configurations. (See 5.1.)

Bearer service is defined as the CI to CI service (e.g., 1.536 Mbit/s unrestricted digital information) that is selected and is carried over a particular bearer channel on an ADSL system. ADSL bearer channels may support a variety of bearer services.

Two methods of signaling protocols for controlling bearer service are recognized for ADSL:

– *In-band signaling:* This is defined as a signaling protocol controlling a bearer service carried over an ADSL bearer channel, where the signaling protocol is within the same ADSL bearer channel as the bearer service. For example, a data protocol stack, such as TCP/IP or OSI, may employ network layer and higher layer signaling protocols within a bearer service transported over ADSL. In-band signaling protocols are carried transparently, and are neither affected nor interpreted by the ADSL system.

– *Out-of-band signaling:* This is defined as a signaling protocol controlling a bearer service carried over an ADSL bearer channel, where the signaling protocol is carried in a different ADSL bearer channel than the bearer service. In this case, the ADSL C channel shall be used to carry the signaling protocol.

When the LS1 duplex channel is used to carry an ISDN BRA (2B+D+overhead) payload, the ISDN BRA multiplex is carried transparently. For the ISDN bearer services carried on the BRA, the signaling is within the BRA D channel and is neither affected nor interpreted by the ADSL system.

15. Loop plant, impairments, and testing

The methods in this clause test ADSL system transmission performance. These laboratory methods evaluate a system's ability to minimize digital bit errors caused by interference from:

- crosstalk coupling from other systems;
- background noise;
- impulse noise;
- POTS signaling.

These potential sources of impairment are simulated in a laboratory set-up that includes test loops, test sets, and interference injection equipment, as well as the test system itself. Figure 37 shows the general arrangement for testing.

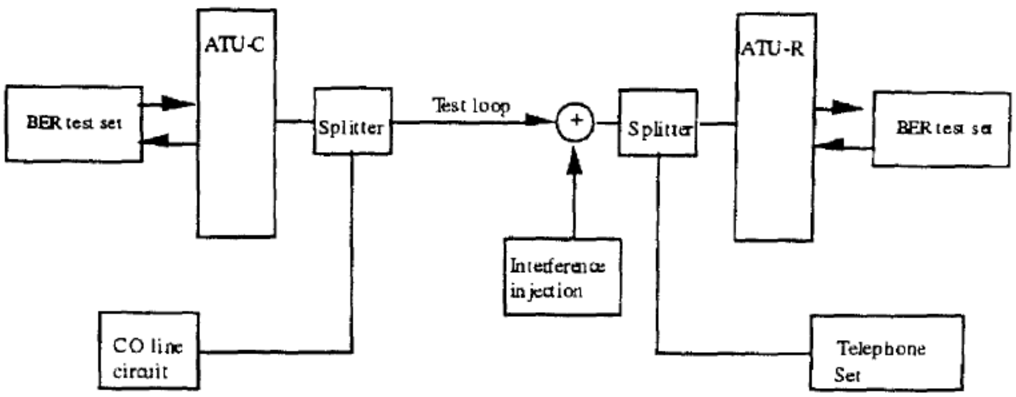


Figure 37 – Overview of test set-up

The crosstalk and impulse noise interfering signals are simulations that are derived from a consideration of real loop conditions and measurements. The test procedure is to inject the interference into the test loops and measure the effect on system performance by a bit error test simultaneously run on the system information channels.

For crosstalk an initial, or reference, power level for the interference represents the expected worst case. If the interference power can be increased without exceeding a specified error threshold, the system has a positive performance margin. Performance margin, expressed in dB, is the difference between the interference level at which the error threshold is reached, and the reference (or 0 dB) level.

The specified error threshold with crosstalk interference is a BER of 10^{-7}; the minimum performance margin is 6 dB.

In the case of impulse noise, an increasing interference level is similarly applied up to the error threshold, and the estimated performance is computed from this information. Because the impulse noise characteristics of the loop plant are not completely understood, the estimation method is based on measured data from several sites. The estimated number of error-causing impulses is compared to a 0.14 % errored-seconds (ES) criterion. The test procedure makes separate determinations of crosstalk margins and impulse error thresholds, although a background crosstalk interference is applied during impulse tests.

The digital channel BER measurement shall be made while including impairments such as POTS signaling interference and crosstalk from other telephone lines. Tests shall be performed using signaling and alerting activities done with an electro-mechanical telephone set and either CO lines or a CO simulator.

15.1 Test loops

ADSL transmission at 1.536 Mbit/s is assessed in terms of performance against an objective of coverage over all copper loops without load coils conforming to Revised Resistance Design (RRD) rules as defined in Bellcore SR-TSV-002275. For test purposes, the RRD loops are represented by loops 7, 9 and 13 specified in 4.5.1 and figure 8 of ANSI T1.601. The primary cable constants are listed in tables G1 - G8 of ANSI T1.601. An additional loop (Loop #0) with a length of less than 10 feet is added to the T1.601 test loops.

ADSL transmission at 6.144 Mbit/s is assessed in terms of performance against an objective of coverage over loops that conform to Carrier Serving Area (CSA) design rules (a subset of RRD loops). For testing purposes, the CSA loops are represented by loops 4, 6, 7, and 8 shown in figures 13 and 14 of Committee T1 Technical Report No. 28.

For 10 or 24 disturber NEXT interference from T1 lines in adjacent binder groups, ADSL transmission is assessed with a mid-CSA loop.

The ADSL control channel and other duplex channels are evaluated with all test loops.

For convenience the configurations of the test loops are shown in figure 38, and their attenuation characteristics are given in annex E.

Table 45 describes a classification that ties together transport payload and loop range based on whether certain options available for the ATU transceivers are used. Category I (basic) describes loop ranges and transport payloads using basic transceivers with no options required. Category II (enhanced) describes loop ranges and transport payloads using options for trellis coding, transmit power boost, and echo cancellation.

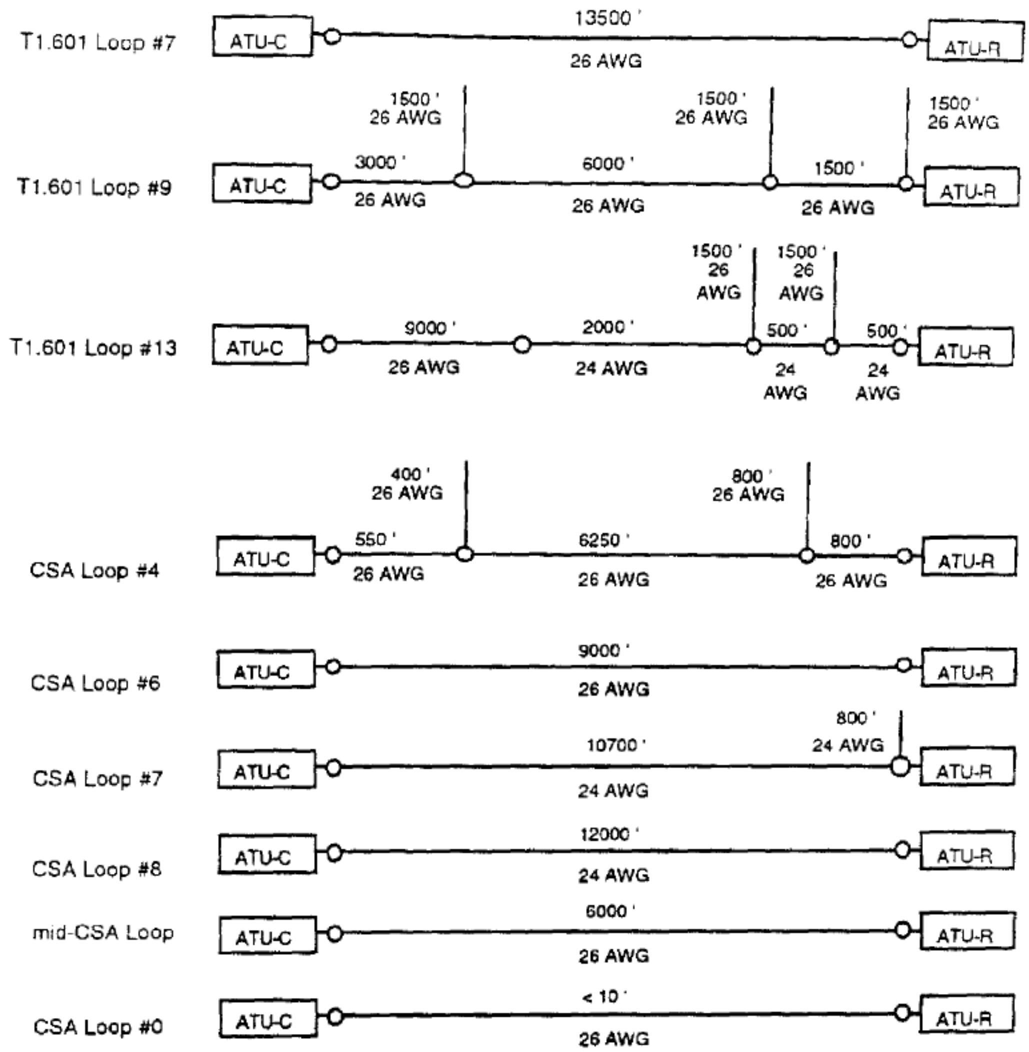
Table 45 – ATU classification by category

Characteristics	Category I (basic)	Category II (optional)
Performance (see note 1)	see note 2	see note 2
Trellis option	off	on required
EC/FDM	optional	EC
Power boost	off	required capable

NOTES:
1. Performance is defined as loop reach shown as a function of bit rate in table 46 and crosstalk as shown in tables 47 - 52.
2. The specific combinations of loops and rates shown in table 46, and crosstalk shown in tables 47–52 shall be tested for either category I or category II ATUs, as indicated.

Table 46 - Loop sets and maximum rates for category I and category II testing

Loop sets	ATU category	Maximum rate (kbit/s) Simplex	Maximum rate (kbit/s) Duplex
T1.601 (7,13)	I	1544	16 + 160
CSA (4,6,7), Mid-CSA	I	6144	64 + 160
T1.601 (7,9,13)	II	1544	16 + 160
CSA (4,6,8), Mid-CSA	II	6144	64 + 576



NOTES
1 AWG = American Wire Gauge
2 Distances are in feet ('): 1000 ' = 0.3048 km.

Figure 38 — Test loops

15.2 Impairments and their simulation in testing

15.2.1 Crosstalk

Crosstalk spectral compatibility is tested using simulations of the interference caused by coupling from other transmission systems sharing the same cable. Four combinations of white noise and NEXT from the following systems are used:

- DSL;
- HDSL;
- ADSL;
- T1 line (adjacent binder group).

For each of these the Power Spectral Density (PSD) of the transmitted signal and of the induced crosstalk is calculated for the appropriate number of disturbers and crosstalk model. The detailed analysis of the PSD and the model are provided in annex B.

The interferers used for the tests are

- 10 or 24 disturber DSL NEXT;
- 10 or 20 disturber HDSL NEXT;
- 10 or 24 disturber ADSL NEXT and FEXT;
- 4, 10 or 24 disturber T1 NEXT (adjacent binder group).

The resulting noise power spectra for these interferers are shown in annex B, where the derivation of the spectrum is described for each of these sources.

15.2.2 Impulse noise

There are two impulse waveforms defined for testing. These are reconstructions of actual recorded impulses observed in field tests, and represent the single the most likely waveforms at specific sites. These wave forms are shown in figures 39 and 40 as approximations only. The two impulse wave forms for testing purposes are described in Annex C with the amplitudes specified at 160 nanosecond intervals.

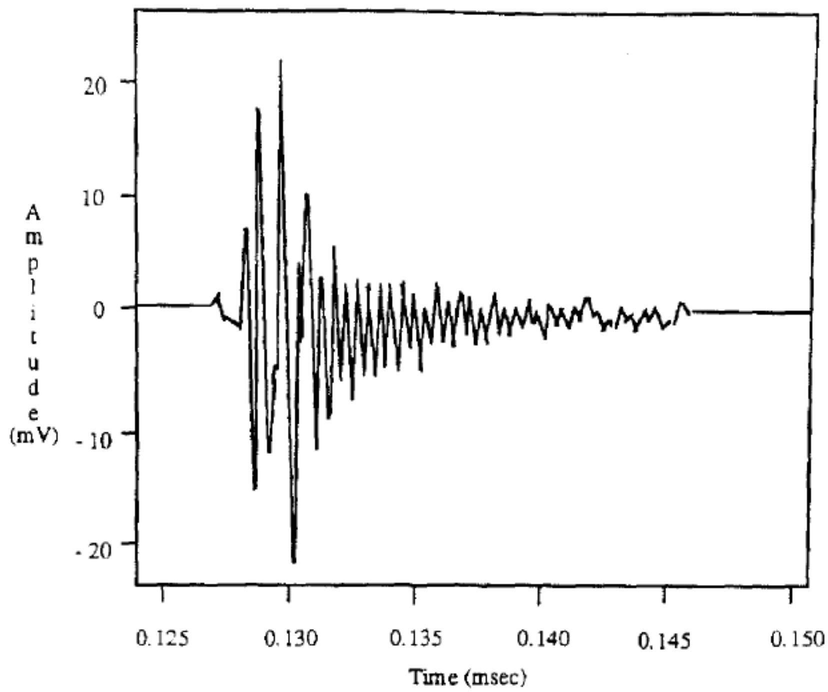


Figure 39 — Test impulse #1

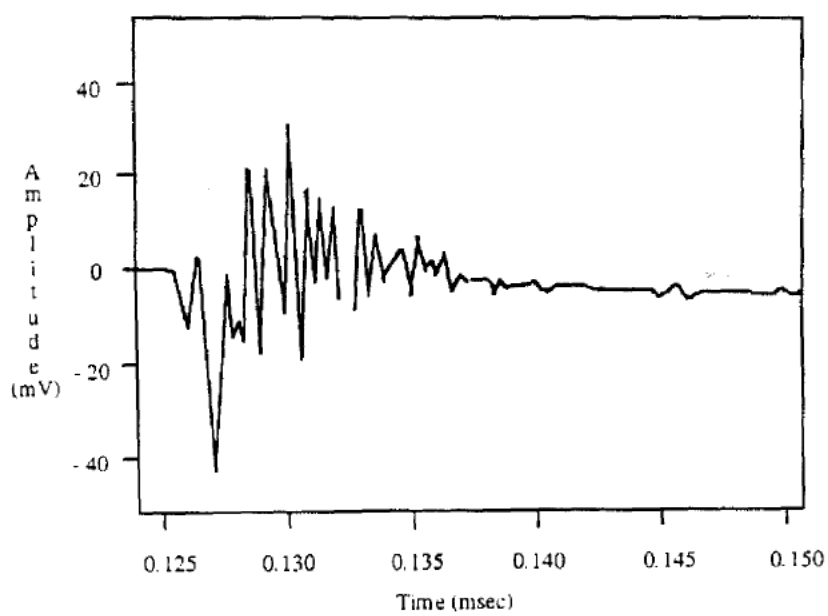


Figure 40 — Test impulse #2

15.3 Test procedures

15.3.1 Test set-up

Figure 41 shows the test setup for measuring performance margins on ADSL systems. The test system consists of a central office transceiver (ATU-C), a remote end transceiver (ATU-R), and associated POTS splitters. The two transceivers are connected together by the test loop. Calibrated simulated crosstalk is injected through a high impedance network across the tip and ring of the loop at the input of one of the transceivers. Impulse noise from a wave form generator is similarly injected. Crosstalk and impulses are injected at the ATU-R for simplex channel tests, and at both the ATU-C and ATU-R for duplex channel tests.

Pseudo-random binary data from the transmitter of the bit error ratio (BER) test set is presented at the simplex channel input of the ATU-C, and the received clock and data outputs from the ATU-R are connected to the receiver of the same or a similar BER test set. The test set measures for BER or errored-seconds (ES), as needed. Similar error testing is done in both directions for the duplex channels at the rates needed for the particular system under test.

A telephone set is connected to the telephone jack of the splitter at the ATU-R end, and a working telephone line circuit is connected to the telephone jack on the splitter at the ATU-C end.

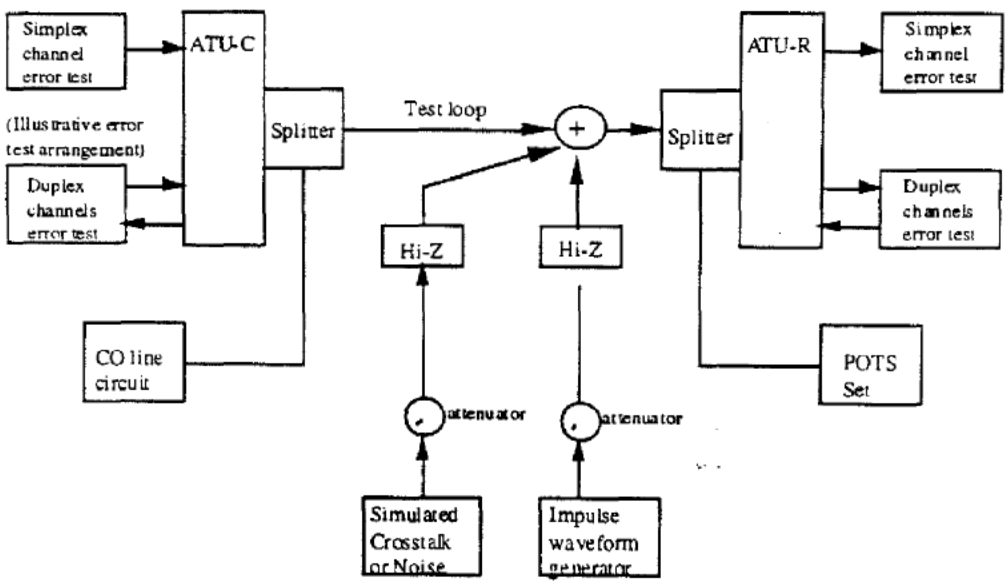


Figure 41 — Laboratory test set-up for measuring performance margins

15.3.1.1 Crosstalk noise injection

Simulated crosstalk, XT (NEXT and/or FEXT) is introduced into the test loop at the ATU-R so as to achieve the appropriate voltage level without disturbing the impedance of the test loop or the transceiver. This is done with a balanced series feed of high impedance. One method for both test and calibration is shown in figure 42. The Thevenin impedance of all noise-coupling circuits connected to the test loop shall be greater than 4000 ohms.

The simulated XT should ideally have the power and spectral density defined by the equations for P_{NEXT} or P_{FEXT} in Annex B. It is acknowledged, however, that if the method of generating the

simulated XT is similar to that shown in figure 42, then its accuracy will depend on the design of the filter used to shape the white noise. Therefore a calculated XT PSD may be defined for which a tolerance on f_0 of ± 2 % is allowed at each null. Then the accuracy of the simulated XT shall be within ± 1 dB of the calculated XT for all frequencies at which the calculated value is less than 45 dB below the peak value. The total power of the simulated XT shall be within ± 0.5 dB of the specified value using the same calibration termination.

The crest factor of the simulated XT shall be equal to or greater than 5.

The simulated XT PSD shall be verified using the calibration termination shown in figure 42 and a selective voltmeter or true RMS meter with a bandwidth of approximately 3 kHz. For DSL and HDSL crosstalk the circuit shall be calibrated for 1.3 dB less crosstalk than specified in Annex B, in order to compensate for the use of 100 ohm terminations instead of 135 ohms.

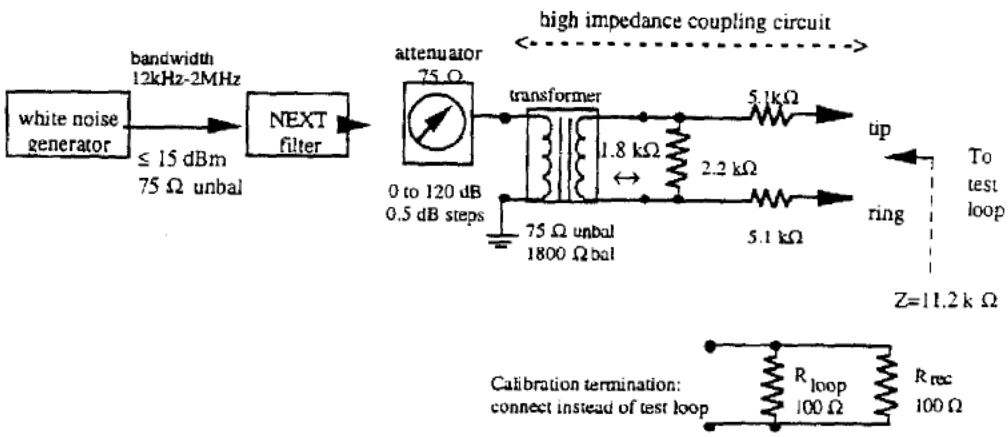


Figure 42 — High impedance crosstalk injection circuit

The charactewristics of the white noise generator in figure 42 are crucial to the accuracy of the tests; consideration should be given to the following factors:

- *The probability distribution of the peak amplitude:* The noise shall be Gaussian within all frequency bands;

- *Crest factor:* This is an indication of the number of standard deviations to which the noise follows a Gaussian distribution; the required minimum is for further study, but is provisionally set at 5.

- *The frequency spectrum:* If the noise is generated using digital methods the sequence repetition rate will affect the correlation of the samples, and hence the frequency spectrum.

15.3.1.2 Impulse noise injection

The same coupling circuit as is used in 15.3.1.1 is used for impulse noise injection. The amplitude level of the impulses may be measured with an oscilloscope.

15.3.1. Error testing

The error test set(s) shall be capable of testing at all channel rates available in the test system (see clause 5). A test pattern of length 2^{23}-1 shall be used.

15.3.2 Test conditions

15.3.2.1 Crosstalk interference

Tables 47 and 48 show the combinations of test loops, numbers of interferers, and data rates to be tested for category I and category II ATUs, respectively.

Table 47- Crosstalk tests for category I

Test loops	Maximum simplex rate (Mbit/s)	Maximum duplex rate (kbit/s)	Margin (dB)	Crosstalk (note) ADSL NEXT and FEXT	HDSL NEXT	DSL NEXT	T1 NEXT adj. binder
T1.601 (7,13)	1.544	16 + 160	6	—	—	24	—
CSA (4)	6.144	64 + 160	6	24	—	24	—
CSA (6)	6.144	64 + 160	6	—	20	—	—
CSA (7)	6.144	64 + 160	6	10	—	10	—
Mid-CSA loop	6.144	64 + 160	3	—	—	—	10

NOTE
The indicated interferers for each test are summed together with AWGN with PSD of −140 dBm/Hz to form a composite power spectral density.

Table 48 - Crosstalk tests for category II

Test loops	Maximum simplex rate (Mbit/s)	Maximum duplex rate (kbit/s)	Margin (dB)	Crosstalk (note 1) ADSL NEXT and FEXT	HDSL NEXT	DSL NEXT	T1 NEXT adj. binder
T1.601 (7,9,13)	1.544	16 + 160	6	—	—	24	—
CSA (4,6,8)	6.144	64 + 576	6	10	10	24	—
CSA (6)	6.144	64 + 576	0	—	—	—	4 (note 2)
Mid-CSA loop	6.144	64 + 576	6	—	—	10	24

NOTES
1. The indicated interferers for each test are summed together with AWGN with PSD of −140 dBm/Hz to form a composite power spectral density.
2. In this case the higher transmit power option may be used.

15.3.2.2 Impulse test

Tables 49 and 50 show the combinations of test loops, interferers, and data rates to be tested.

Table 49 - Test loops, interferers, and data rates for impulse tests for category I

Test Loops	Duplex rate (Mbit/s)	Simplex rate (kbit/s)	Interferers		
			Impulse 1	Impulse 2	crosstalk (note)
T1.601 (7,13)	1.544	16 + 160	y	y	y
CSA (4,6,7)	6.144	64 + 160	y	y	y
Mid-CSA (6 kft)	6.144	64 + 160	y	y	y

NOTE - The type of crosstalk interference applicable for each test is taken from the corresponding test in table 47. The total power of the applied interference shall be fixed at 4 dB below the reference level.

Table 50 - Test loops, interferers, and data rates for impulse tests for category II

Test Loops	Duplex rate (Mbit/s)	Simplex rate (kbit/s)	Interferers		
			Impulse 1	Impulse 2	crosstalk (note)
T1.601 (7,9,13)	1.544	16 + 160	y	y	y
CSA (4,6,8)	6.144	64 + 576	y	y	y
Mid-CSA (6 kft)	6.144	64 + 576	y	y	y

NOTE - The type of crosstalk interference applicable for each test is taken from the corresponding test in table 48. The total power of the applied interference shall be fixed at 4 dB below the reference level.

15.3.2.3 POTS

The interference due to POTS service on the same line is generated by use of actual telephones and central office circuits connected in the normal way to the system under test. The following POTS signaling and alerting activities shall be performed:

- call phone at ATU-R and allow to ring 25 times;
- pick up ringing phone at ATU-R, 25 times;
- perform off-hook and on-hook activity on phone at ATU-R, 25 times;
- perform pulse and tone dialing.

Tables 51 and 52 show the combinations of test loops, interferors, and data rates to be tested for categories I and II.

Table 51 - Test loops, interferers, and data rates for POTS tests category I

Test loops	Maximum simplex rate	Maximum duplex rate	Interferers	
			POTS signaling	Crosstalk (note)
ANSI (7,13)	1.544 Mbit/s	16 + 160 kbit/s	y	y
CSA (4,6,7)	6.144 Mbit/s	64 + 160 kbit/s	y	y
Mid-CSA loop	6.144 Mbit/s	64 + 160 kbit/s	y	y
NOTE - The type of crosstalk interference applicable for each test is taken from the corresponding test in table 46. The total power of the applied interference shall be fixed 4 dB below the reference or 0 dB margin level.				

Table 52 - Test loops, interferers, and data rates for POTS tests category II

Test loops	Maximum simplex rate	Maximum duplex rate	Interferers	
			POTS signaling	Crosstalk (note)
ANSI (7,9,13)	1.544 Mbit/s	16 + 160 kbit/s	y	y
CSA (4,6,8)	6.144 Mbit/s	64 + 576 kbit/s	y	y
CSA (6)	6.144 Mbit/s	64 + 576 kbit/s	y	y
Mid-CSA loop	6.144 Mbit/s	64 + 576 kbit/s	y	y
NOTE - The type of crosstalk interference applicable for each test is taken from the corresponding test in table 48. The total power of the applied interference shall be at a fixed level of 4 dB down from the reference or 0 dB margin level.				

15.3.3 Test methods

With the test set-up as shown in figure 42, the test combinations described in 15.3.2 shall be tested as follows:

15.3.3.1 Crosstalk

Before testing, the ADSL units are trained with the crosstalk interference specified in 15.2.2 and 15.3.2.1 present. The simulated crosstalk power is injected at the appropriate reference level. The power levels given in 15.2.1 for each type of crosstalk are considered the 0 dB margin for that type and number of disturbers. For example, the 0 dB margin level for 24-disturber DSL crosstalk was -52.6 dBm. Margin measurements are made by changing, in whole dB steps, the power level of the crosstalk injected at the transceiver and monitoring the BER over the test loops. A tested system has positive margin for a given type of crosstalk on a given loop if the system was able to operate at a BER ≤ 1E-7 with injected crosstalk power greater than the 0 dB margin level.

The criteria for margin level determination shall include a check that the ADSL unit can train at the margin level.

The minimum testing times to determine BERs with 95% confidence are shown in table 53.

Table 53 - Minimum test time for crosstalk

Bit Rate	Minimum test time
above 6 Mbit/s	100 seconds
1.544 Mbit/s to 6 Mbit/s	500 seconds
less than 1.544	20 minutes

15.3.3.2 Impulse noise

Before testing, the ADSL units are trained with the crosstalk interference specified in 15.3.2.2 present. The test procedure consists of injecting the selected impulse wave form at varying amplitude levels and random phase. At each level the impulse is applied 15 times with a spacing of at least one second while an error measurement is made on the ADSL channels. The amplitude (u_e) in millivolts at which half the impulses cause an error is determined for each wave form

Using the above amplitude determinations , the following equation gives the estimated probability that a second will be errored:

$$E = 0.0037\ P(u>u_e1) + 0.0208\ P(u>u_e2)$$

where: $P(u>u_e) = \frac{25}{u_e^2}$, for $5\ \text{mV} \le u_e \le 40\ \text{mV}$

$P(u>u_e) = \frac{0.625}{u_e}$, for $u_e > 40\ \text{mV}$

u_e1 refers to waveform 1

u_e2 refers to waveform 2

The resulting value shall be less than the es criterion of 0.14%.

15.3.3.3 POTS interference

Before testing, the ADSL units are trained with the crosstalk interference specified in 15.3.2.3 present. Signaling disturbances are created through use of the CO line connected to the splitter at the ATU-C, and the telephone set connected to the telephone jack of the splitter at the ATU-R. During these activities, monitor the ADSL channels while noting any test conditions that cause errored seconds.

16. Physical characteristics

16.1 Wiring polarity integrity

ADSL operation shall be independent of the polarity of the pair of wires connecting the ATU-C and ATU-R.

16.2 Connector

For single mountings, the connection of the POTS splitter to the existing CI wiring interface shall be as specified in table 54 and shown in figure 43 using an 8 pin plug and jack (RJ31X) equipped with shorting bars. In this configuration the cord connecting the POTS splitter and ATU-R unit shall be hard wired. The use of a separate POTS splitter physically separated from the ATU-R is not precluded by this standard. The layer 1 requirements for the ATU-R-to-splitter interface may be defined in a later issue of the standard. For multiple mountings, other connection arrangements may be appropriate.

Table 54 – Pin assignments for 8-position jack and plug (RJ31X) at U-R

Pin No.	Assignment For Jack	Assignment For Plug
1	Tip or ring to POTS distribution	Tip or ring to POTS splitter (out)
2	No connection	No connection
3	No connection	No connection
4	Tip or ring from network interface	Tip or ring to POTS splitter (in)
5	Tip or ring from network interface	Tip or ring to POTS splitter (in)
6	No connection	No connection
7	No connection	No connection
8	Tip or ring to POTS distribution	Tip or ring to POTS splitter (out)

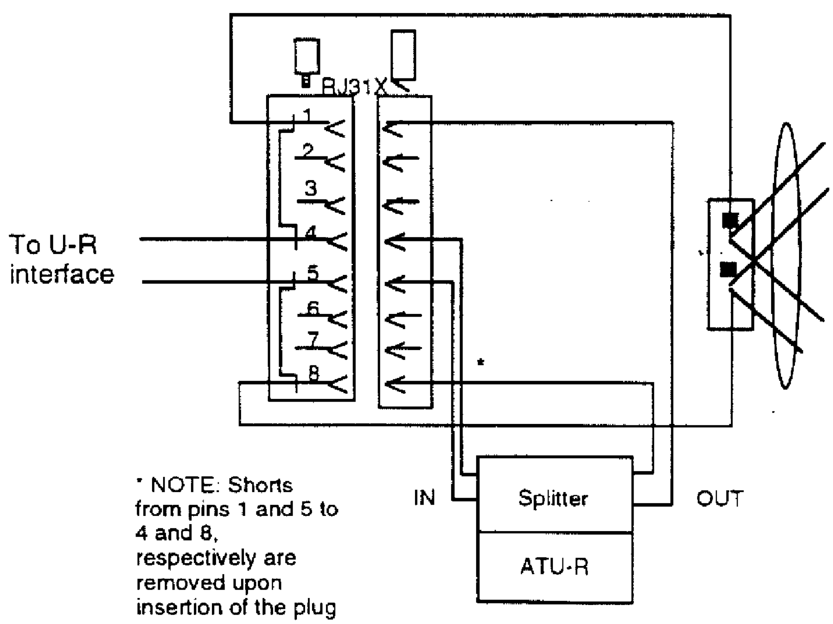


Figure 43 — Interface on the customer premises side of the U-R

16.3 Wiring requirements for a remotely located POTS splitter/ATU-R

It is recommended for a remotely located POTS splitter/ATU-R unit that the plug and jack arrangement specified in 16.2 be used . The connections between plug 1 and jack 2 are as specified in table 55, and illustrated in figure 44. The pin connections for plug 2 shall be as specified in table 54. In this configuration the cord connecting the POTS splitter and ATU-R unit shall be hard wired.

Table 55 - Pin assignments for 8-position jack and plug at remote location

Pin No.	Assignment For Jack 2
1	From pin 1 of plug 1 to pin 1 of jack 2
2	No connection
3	No connection
4	From pin 4 of plug 1 to pin 4 of jack 2
5	From pin 5 of plug 1 to pin 5 of jack 2
6	No connection
7	No connection
8	From pin 8 of plug 1 to pin 8 of jack 2

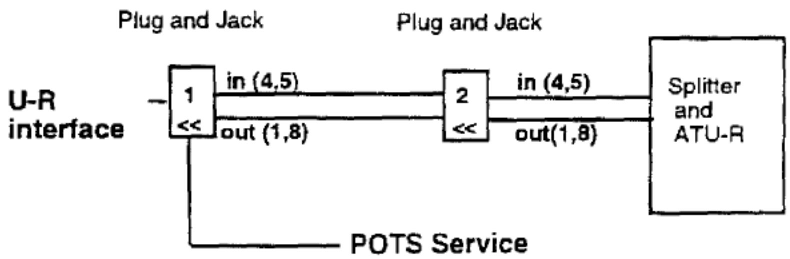


Figure 44 — Wiring for a remotely located POTS splitter/ATU-R

16.4 Maximum distance for a remotely located unit

The distance between plug and jack 1 and the remotely located POTS splitter and ATU-R unit shall not exceed (for further study) feet when the two the pairs, (4,5) and (1,8), are in a common sheath.

17. Environmental conditions

17.1 Protection

Material referring to protection may be found in annex F of this standard.

17.2 Electromagnetic compatibility

Material referring to electromagnetic compatibility may be found in annex F of this standard.

Annex A
(normative)

ATU-C and ATU-R state diagrams

A.1 Introduction

This annex provides state diagrams for the ATU-C and ATU-R, some portions of which are mandatory to guarantee interworking between different manufacturers' units, and some portions of which are presented here as an example only--their functions may be required or desired, but the implementation is left to the vendor.

A.2 Definitions

The following terms and abbreviations are used in this annex. Where states or events have been defined elsewhere in this standard, the definitions are referenced here for convenience.

– C-ACT:	See 12.2.2;
– C-TONE:	See 12.2.1.3;
– R-ACT-REQ:	See 12.3.1;
– R-ACK:	See 12.3.3;
– lof-rs:	Loss of ADSL frame synch/resync event. This event occurs when some algorithm, which may be vendor-specific, determines that a resync attempt is required. Note that this lof-rs event is probably (but not required to be) related to the sef (severely errored frame) defect defined for operations and maintenance (11.3).
– LOF:	Loss of ADSL frame synchronization declared after sef time-out (near-end severely errored frame defect, defined in 11.3).
– LOS;	Loss of received signal at "U" interface declared after los time-out (near-end loss of received signal defect, defined in 11.3).
– high BER:	High bit error rate in received data: detected by thresholding #crc errors (near-end crc-8i and crc-8ni error anomalies, defined in 11.3) over some period of time.
– host control channel	An ATU-C configuration control channel from some host controller, such as an ACOT (ADSL Central Office Terminal), which controls one or more ATU-C line units. Note that this channel has no relationship or direct interworking with the 64 or 16 kbit/s "C" bearer channel, which is sometimes also called a control channel.
– reconfig1:	A channelization reconfiguration that can be accomplished without resetting certain key portions of the data framing, transmitter, or receiver functions (clauses 6 and 7), and thus can be performed without disrupting channels that would not change as a result of the reconfiguration. For example, if four 1.536 Mbit/s simplex channels are currently active and are all allocated to the interleave data buffer, then a reconfiguration that requires two of them to remain active, and the other two to be replaced by a 3.088 Mbit/s channel would qualify as a reconfig1.
– reconfig2:	A channelization reconfiguration that requires resetting of some key portion of the data framing, transmitter, or receiver functions (clauses 6 and 7), and which thus cannot be achieved without loss of some user data. This reconfiguration request will require a fast retrain. Examples are: – a change from the default bearer channel rates to optional rates, such as a request for a reconfiguration from a single 6.144 Mbit/s simplex bearer to a 6.312 Mbit/s simplex bearer, which requires a change in aggregate transmitted bit rate, FEC codeword size, and resetting the interleave/deinterleave functions;

– if four 1.536 Mbit/s simplex channels are currently active and are all allocated to the interleave data buffer, then a reconfiguration that requires one or more of them to move to the fast data buffer would require a fast retrain to allocate the extra AEX byte for the fast data buffer, to change the FEC codeword parameters of the interleaved data buffer, and to reset the interleave/deinterleave functions.

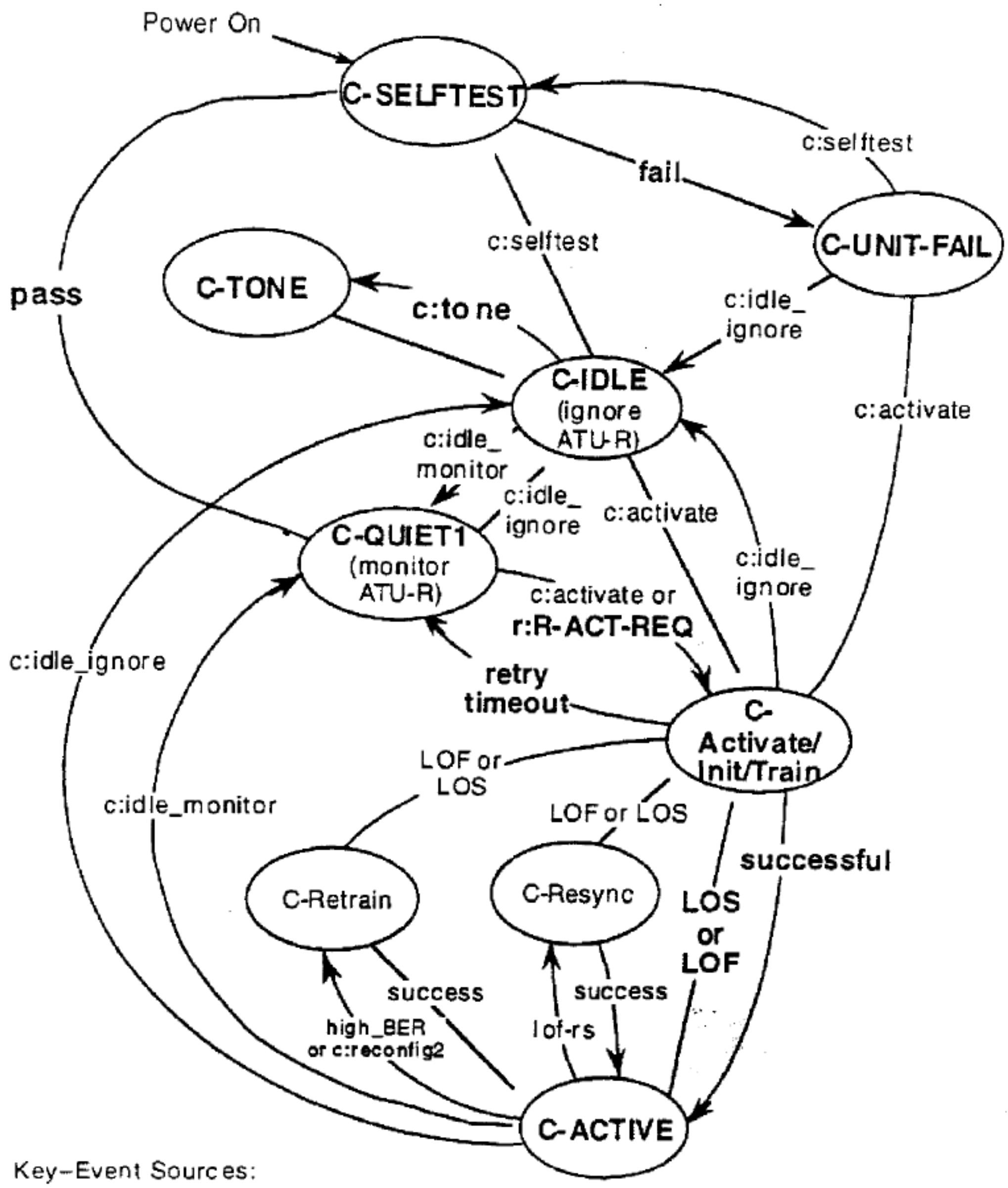
A.3 State diagrams

State diagrams are given in figure A.1 for the ATU-C, and in figure A.2 for the ATU-R. States are indicated by ovals, with the name of the state given within the oval. The states are defined in table A.1 for the ATU-C and in table A.2 for the ATU-R. Transitions between states are indicated by arrows, with the event causing the transition listed next to the arrow. For some events, the source of the event is indicated with letter(s) and a colon preceding the event name; a key to the source events is provided at the bottom of each figure. Mandatory states and events are indicated with **boldface type**; those states and events in normal face type are provided here as an example, with the form of their implementation left to the vendor.

In the state diagram for the ATU-C, a C-IDLE state would be desired to guarantee a quiet mode, which may be useful prior to provisioning, to allow certain tests (e.g., MLT), or to discontinue service. A selftest function is desirable, but it may be a vendor/customer option to define when selftest occurs (e.g., always at power-up or only under CO control), and which transition to take after successfully completing selftest (e.g., enter C-IDLE, or enter C-QUIET1, or enter C-Activate/Init/Train).

A variety of "host controller" commands (events preceded by "c:") are shown as non-mandatory in the ATU-C state diagram to provide example events and transitions between states. The way in which these events are implemented is left to the vendor, since many options are possible (e.g., separate host controller port on the ATU-C, switches or other front-panel controls, fixed options).

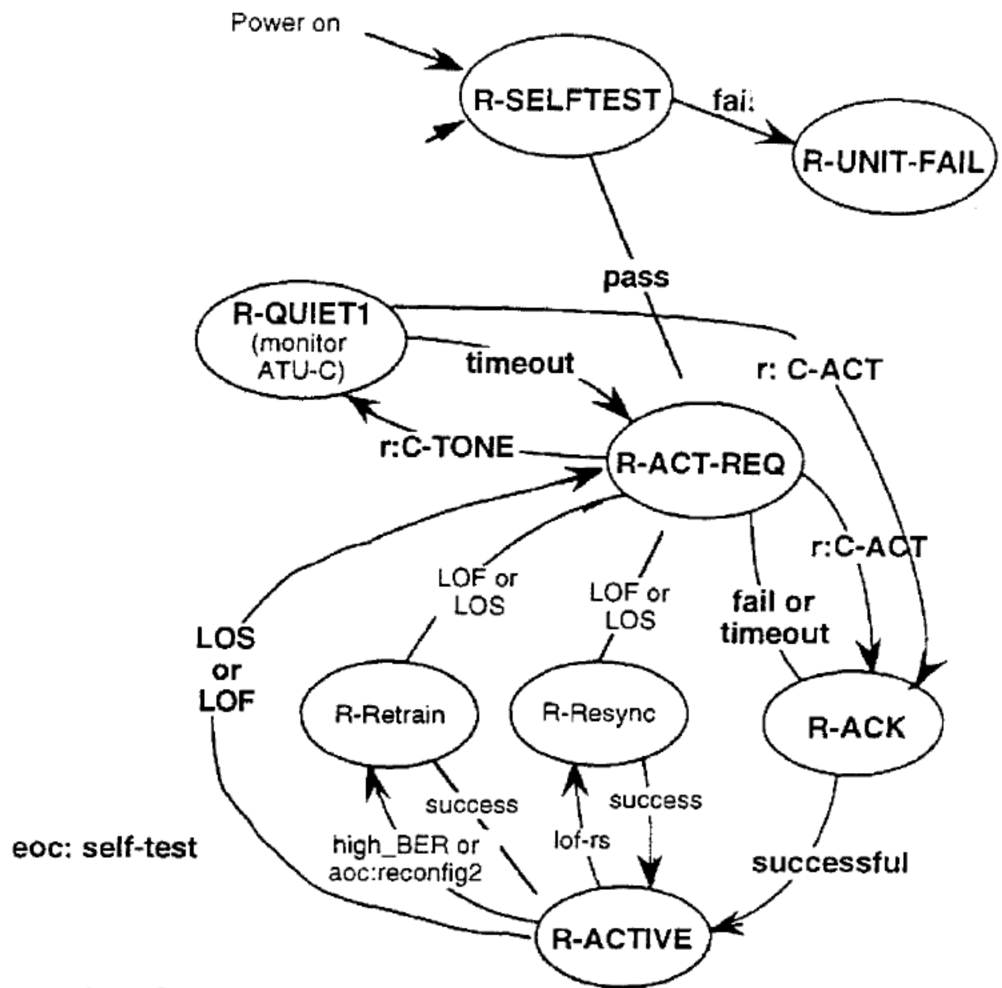
A "Retrain" state is shown as non-mandatory in both state diagrams (fast retrain is still under study). A "Resync" state is shown as non-mandatory in both state diagrams, to be left as a vendor option that may use vendor proprietary algorithms.



Key–Event Sources:
c:____ host controller command
r:____ received from ATU-R

State Definitions in table A-1
Terms defined in clause A.1

Figure A.1 - State diagram for the ATU-C



Key -- Event Sources:
r: received from ATU-C
eoc: embedded operations channel command
aoc: ADSL overhead control channel command

State Definitions in table A-2
Terms defined in clause A.1

Figure A.2 - State diagram for the ATU-R

Table A.1 - ATU-C state definitions

State Name	Description
C-SELFTEST	Unit performs selftest. Transmitter and receiver off (quiet at U-C interface); no response to host control channel (e.g., ACOT)
C-UNIT-FAIL	(selftest failed) Monitor host control channel if possible (could allow ATU host controller to retrieve selftest results)
C-IDLE (12.2.2) (Idle; ignore ATU-R)	Transmitter and receiver off (no response to R-ACT-REQ). Monitor host control channel
C-TONE	Transmit C-TONE tone and transition back to C-IDLE
C-QUIET1 (12.2.1) (Idle; monitor ATU-R)	Transmitter off Receiver on, monitoring for R-ACT-REQ; if detected, transition to C-Activate/Init/Train state Monitor host control channel

C-Activate/Init/Train
(Starts with State C-ACT of 12.2; includes 12.2, 12.4, 12.6, 12.8)
	Initialize Train_Try_Counter
	while (--Train_Try_Counter >= 0)
	{ Transmit C-ACT (12.2.2)
	Start timer
	If receive R-ACK before timer expires
	proceed with initialization/training
	If successful, transition to C-ACTIVE
	}
	Transition to C-QUIET1

C-ACTIVE (Steady State Data Transmission; 6, 11.2, 11.3, 13)	Perform steady state bit pump functions (user data channels active) Allow bit swaps and non-intrusive reconfigurations (reconfig1) Monitor host control channel Monitor alarms, eoc, aoc If LOS or LOF event, transition to C-Activate/Init/Train
C-Resync (non-mandatory; vendor proprietary)	(State is entered when some algorithm, possibly based on loss of ADSL synch framing, determines that resync is required) Declare sef (defined in 11.3)--user data transmission has been disrupted If signal present (i.e., not los) Attempt to find synch pattern and realign (vendor proprietary) If successful, remove sef and transition to C-ACTIVE else time-out on sef, declare LOF event, transition to C-Activate/Init/Train else time-out on los, declare LOS event, transition to C-Activate/Init/Train

C-Retrain (fast retrain for further study)	(State can only be entered if received signal is still present and if ADSL frame synch is still maintained) Declare sef (defined in 11.3)--user data transmission has been disrupted If signal present (i.e., not los) Channel ID and bit allocation calculation Reset Data Framing and V-interface circuits If successful, remove sef and return to C-ACTIVE else time-out on sef, declare LOF event, transition to C-Activate/Init/Train else time-out on los, declare LOS event, transition to C-Activate/Init/Train

Table A.2 - ATU-R state definitions

State Name	Description
R-SELFTEST	Unit performs selftest. Transmitter and receiver off (quiet at U-R interface). If selftest passes, transition to R-ACT-REQ else transition to R-UNIT-FAIL
R-UNIT-FAIL	(selftest failed--no exit from this state, except to cycle power)

R-ACT-REQ
(12.3.1)
	Receiver on, monitoring for C-ACT or C-TONE
	while (C-ACT not received AND C-TONE not received)
	{ Transmit R-ACT-REQ for 128 symbols (see 12.3.1)
	No transmission for 896 symbols
	}
	If (C-ACT was received) transition to R-Init/Train
	If (C-TONE was received) transition to R-QUIET1

R-QUIET1 (12.3.2) (Idle; monitor ATU-C)	Transmitter off; Receiver on, monitoring for C-ACT Start timer (60 seconds, see 12.3.2) At timeout transition to R-ACT-REQ
R-Init/Train (Starts with State R-ACK of 12.3; includes 12.3, 12.5, 12.7, 12.9)	Transmit R-ACK Proceed with Initialization and Training Sequence If successful, transition to R-ACTIVE else transition to R-ACT-REQ
R-ACTIVE (Steady State Data Transmission; 7, 11.2, 11.3, 13)	Perform steady state bit pump functions (user data channels active) Allow bit swaps and non-intrusive reconfigurations (reconfig1) Monitor alarms, eoc, aoc If LOS or LOF event, transition to R-ACT-REQ
R-Resync (non-mandatory; vendor proprietary)	(State is entered when some algorithm, probably based on loss of ADSL synch framing, determines that resync is required) Declare sef (defined in 11.3)--user data transmission has been disrupted If signal present (i.e., not los) Attempt to find synch pattern and realign (vendor proprietary) If successful, remove sef and transition to R-ACTIVE else time-out on sef, declare LOF event, transition to R-ACT-REQ else time-out on los, declare LOS event, transition to R-ACT-REQ

R-Retrain (fast retrain for further study)	(State can only be entered if received signal is still present and if ADSL frame synch is still maintained) Declare sef (defined in 11.3)--user data transmission has been disrupted Reset Data Framing and T-interface circuits If signal present (i.e., not los) Channel ID and bit allocation calculation If successful, remove sef and transition to R-ACTIVE else time-out on sef, declare LOF event, transition to R-ACT-REQ else time-out on los, declare LOS event, transition to R-ACT-REQ

Annex B
(normative)

Power spectral density of crosstalk disturbers

Crosstalk margin measurements were made for four types of disturbers, DSLs, HDSLs, T1s and ADSL lines. DSL, HDSL, and ADSL crosstalk is from pairs within the same binder group; T1 crosstalk is from pairs in an adjacent binder group.

B.1 Simulated DSL power spectral density and induced NEXT

The power spectral density (PSD) of Basic Access DSL disturbers is expressed as:

$$PSD_{\ DSL\text{-}Disturber} = K_{DSL} \times \frac{2}{f_o} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^4}, \qquad f_{3dB} = 80\ kHz,\ 0 \le f < \infty$$

where $f_o = 80\ kHz,\ K_{DSL} = \frac{5}{9} \times \frac{V_p^2}{R},\ V_p = 2.50$ Volts and R = 135 Ohms

This equation gives the single-sided PSD; that is, the integral of PSD, with respect to f, from 0 to infinity, gives the power in Watts. $PSD_{\text{DSL-Disturber}}$ is the PSD of an 80 kbaud 2B1Q signal with random equiprobable levels, with full-baud square-topped pulses and with 2nd order Butterworth filtering (f_{3dB} = 80 kHz).

The PSD of the DSL NEXT can be expressed as:

$$PSD_{\text{DSL-NEXT}} = PSD_{\text{DSL-Disturber}}\left(x_n f^{\frac{3}{2}}\right) \qquad 0 \le f < \infty,\ n = 1,\ 10,\ 24,\ 49$$

where $x_N = 0.882 \times 10^{-14} \times N^{0.6}$

The integration of $PSD_{\text{DSL-Disturber}}$ and $PSD_{\text{DSL-NEXT}}$ over various frequency ranges of interest are presented in table B.1.

Table B.1 - DSL transmit and induced NEXT power

Frequency Range	Transmit Power dBm	Next power dBm 10 disturbers	NEXT Power dBm 24 disturbers
0≅0.16 MHz	13.6	-54.9	≅52.6
0≅0.32 MHz	13.6	-54.9	≅52.6
0≅1.544 MHz	13.6	-54.9	≅52.6

Figure B.1 shows the theoretical PSD of 24 Disturber DSL NEXT.

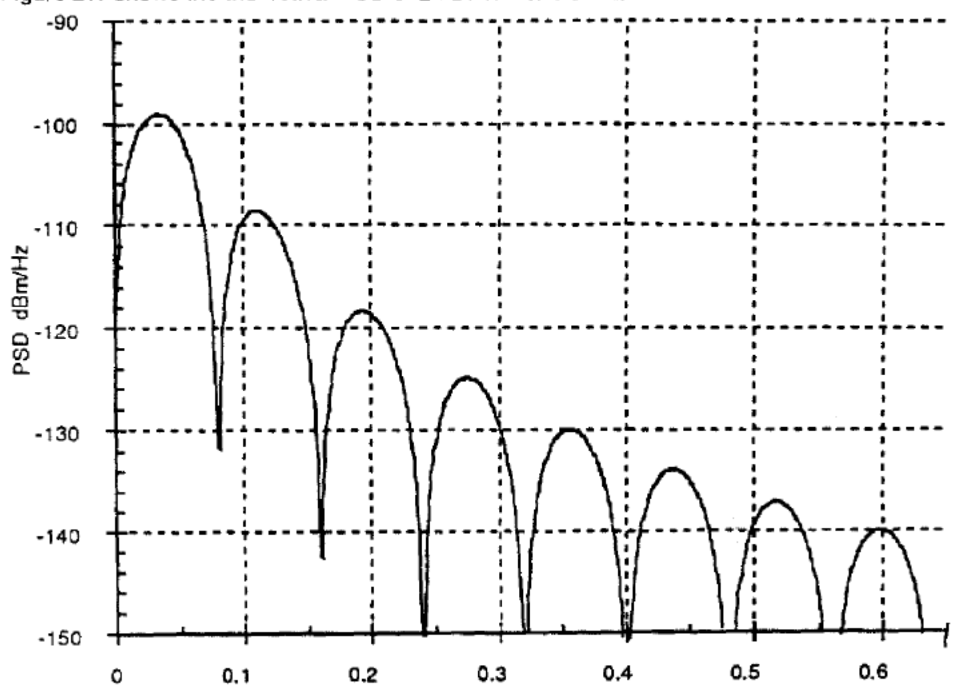


Figure B.1 24-disturber DSL NEXT

B.2 Simulated HDSL power spectral density and induced NEXT

The PSD of HDSL disturbers is expressed as:

$$PSD_{\text{HDSL-Disturber}} = K_{\text{HDSL}} \times \frac{2}{f_o} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2} \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^8}, \qquad f_{3\text{dB}} = 196 \text{ kHz}, \; 0 \le f < \infty$$

where $f_o = 392\,\text{kHz}$, $K_{\text{HDSL}} = \frac{5}{9} \times \frac{V_p^2}{R}$, $V_p = 2.70$ Volts, and R = 135 Ohms

This equation gives the single-sided PSD; that is, the integral of PSD, with respect to f, from 0 to infinity, gives the power in Watts. $PSD_{\text{HDSL-Disturber}}$ is the PSD of a 392 kbaud 2B1Q signal with random equiprobable levels, with full-band square-topped pulses and with 4-th order Butterworth filtering (f_{3dB} = 196 kHz).

The PSD of the HDSL NEXT can be expressed as:

$$PSD_{\text{HDSL-NEXT}} = PSD_{\text{HDSL-Disturber}} \left(x_n f^{\frac{3}{2}} \right), \qquad 0 \le f < \infty, \; n = 1, \; 10, \; 24, \; 49$$

where x_1, x_{10}, x_{24}, and x_{49} are defined in B.1

The integration of $PSD_{\text{HDSL-Disturber}}$ over various frequency ranges of interest is presented in table B.2 along with the induced NEXT power.

Table B.2 - HDSL transmit and induced NEXT power

Frequency Range	Transmit Power dBm	NEXT Power 10 disturbers dBm	NEXT Power 20 disturbers dBm
0≅0.196 MHz	13.4	≅46.9	-45.1
0≅0.392 MHz	13.6	≅46.3	-44.5
0≅0.784 MHz	13.6	≅46.3	-44.5
0≅1.544 MHz	13.6	≅46.3	-44.5
0≅1.568 MHz	13.6	≅46.3	-44.5

Figure B.2. shows the theoretical PSD of 10-Disturber HDSL NEXT.

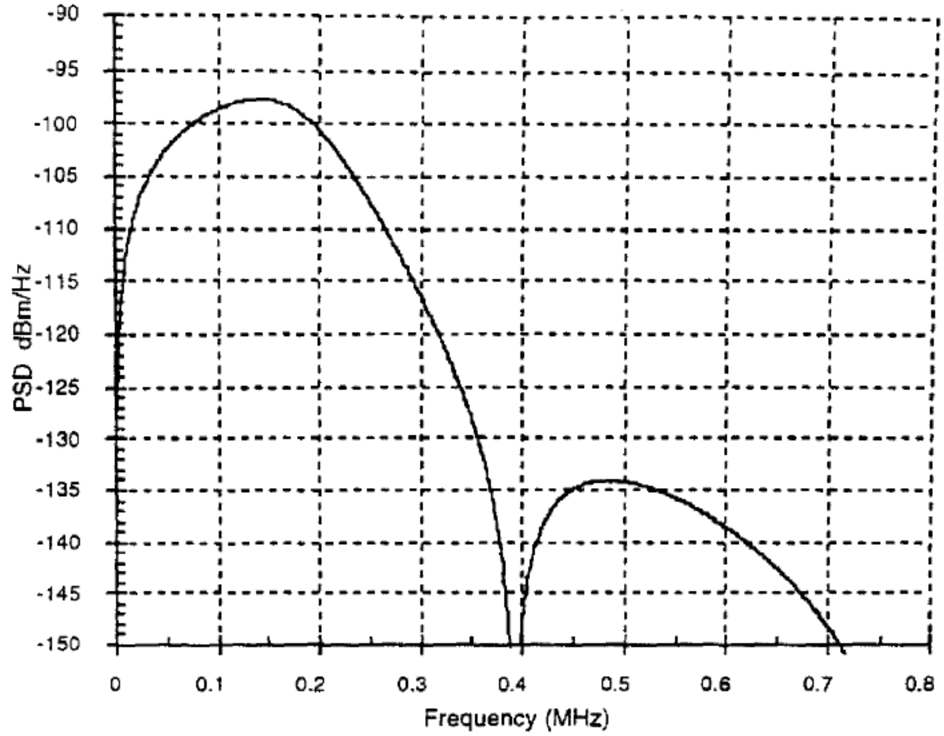


Figure B.2 ≡ 10≡disturber HDSL NEXT

B.3 Simulated T1 line power spectral density and induced NEXT

The PSD of the T1 line disturber is assumed to be the 50% duty–cycle random Alternate Mark Inversion (AMI) code at 1.544 Mbit/s. The single–sided PSD has the following expression.

$$PSD_{T1-Disturber} = \frac{V_p^2}{R_L} \times \frac{2}{f_o} \left[\frac{\sin\left(\frac{\pi f}{f_o}\right)}{\left(\frac{\pi f}{f_o}\right)} \right]^2 \sin^2\left(\frac{\pi f}{2 f_o}\right) \times \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^6} \times \frac{f^2}{f^2 + f_3dB^2}, \qquad 0 \le f < \infty$$

The total power of the transmit T1 signal is computed by:

$$P_{T1-total} = \frac{1}{4}\frac{V_p^2}{R_L}$$

It is assumed that the transmitted pulse passes through a low–pass shaping filter. The shaping filter is chosen as a third order low–pass Butterworth filter with 3 dB point at 3.0 MHz. The filter magnitude squared transfer function is:

$$\left|H_{shaping}(f)\right|^2 = \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^6}$$

In addition, the coupling transformer is modeled as a high–pass filter with 3 dB point at 40 kHz as:

$$\left|H_{Transformer}(f)\right|^2 = \frac{f^2}{f^2 + f_{3dB}{}^2}$$

Furthermore, it is assumed that V_p = 3.6 Volts, R_L = 100 Ohms, and f_0 = 1.544 MHz.

The PSD of the T1 NEXT can be expressed as:

$$PSD_{T1-NEXT} = PSD_{T1-Disturber}\left(x_n f^{\frac{3}{2}}\right), \qquad 0 \le f < \infty,\ n = 4,\ 10,\ 24$$

where x_4, x_{10}, and x_{24} are defined in B.1

The T1 transmit and induced NEXT powers using n–crosstalk models (X_n) are presented in table B.3, and the PSDs of 4, 10, and 24 T1 NEXT disturbers are shown in figure B.3.

Table B.3 – T1 transmit and induced NEXT power with shaping and coupling transformer

Frequency Range	Transmit Power dBm	NEXT Power 4 disturbers dBm	NEXT Power 10 disturbers dBm	NEXT Power 24 disturbers dBm
0–1.544 MHz	14.1	–50.2	–47.8	–45.5
0–3 MHz	14.6	–48.3	–45.9	–43.6
0- 10 MHz	14.6	- 48.0	-45.6	-43.3

For testing, the T1 NEXT powers in table B.3 and PSD curves in figure B.3 have been adjusted downward by a total of 15.5 dB to take account of (a) the reduced coupling from an adjacent binder group (10 dB) and (b) an average separation between disturbing T1 transmitter and ADSL receiver (5.5 dB)

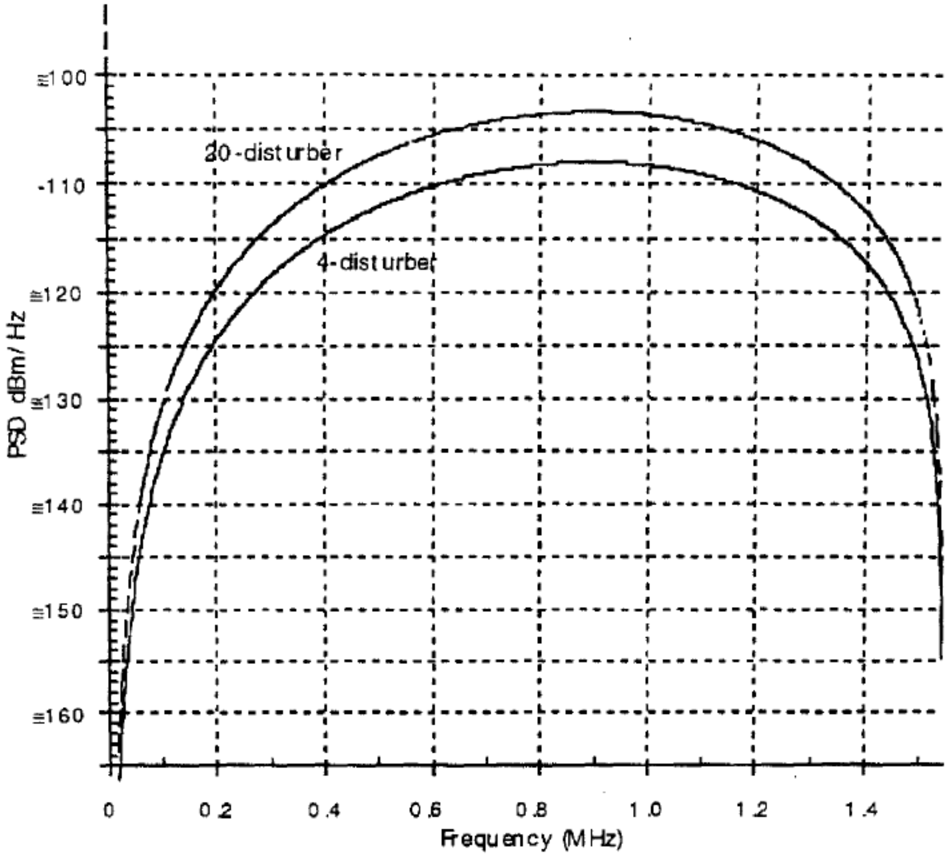


Figure B.3 4 and 20≅disturber T1 NEXT

B.4 Simulated ADSL power spectral density and induced FEXT

The PSD of ADSL disdurbers is expressed as:

$$PSD_{\text{ADSL-Disturber}} = K_{\text{ADSL}} \times \frac{2}{f_o} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2} \times |LPF(f)|^2 \times |HPF(f)|^2 , \qquad 0 \le f < \infty$$

where $f_o = 2.208 \times 10^6\,\text{Hz}$, $K_{\text{ADSL}} = 0.1104\,Watts.$

This equation gives the single sided PSD, where K_{ADSL} is the total transmitted power in Watts for the downstream ADSL transmitter before shaping filters, and is set such that the ADSL PSD will not exceed the maximum allowed PSD. f_0 is the sampling frequency in Hz and

$$|LPF(f)|^2 = \frac{1}{1+\left(\frac{f}{f_{3dB}}\right)^8} , \qquad f_{3dB} = 1.104 \times 10^6\,Hz$$

is a fourth order low pass filter with a 3 dB point at 1104 kHz, and

$$|HPF(f)|^2 = \frac{f^8}{f^8 + f_{3dB}{}^8} , \qquad f_{3dB} = 20\text{x}10^3\,Hz$$

is a fourth order high pass filter with a 3 dB point at 20 kHz, separating ADSL from POTS. With this set of parameters the PSD_{ADSL} is the PSD of a downstream transmitter that uses all the channels.

The FEXT loss model is:

$$|H_{\text{FEXT}}(f)|^2 = |H_{\text{channel}}(f)|^2 \times k \times l \times f^2$$

where H_{channel} (f) is the channel transfer function, *k* is the coupling constant and is 3.083x10≡20 for 10, 1% worst-case disturbers, *l* is the coupling path length in feet and equals 9000 ft for CSA #6, and *f* is in Hz. The FEXT noise PSD is therefore:

$$PSD_{\text{ADSL - FEXT}} = PSD_{\text{ADSL}} \times |H_{\text{FEXT}}(f)|^2$$

The integration of PSD_{ADSL} and $PSD_{\text{ADSL≡FEXT}}$ over the various frequency ranges is shown in table B.4.

Table B.4 ≡ PSDADSL and PSD$_{\text{ADSL≡FEXT}}$ power with shaping and coupling transformer

Frequency Range	Transmit Power dBm	FEXT Power 10 disturbers dBm	FEXT power 24 dsiturbers dBm
0≡1.104 MHz	19.0	≡69.6	-67.3
0≡2.204 MHz	19.2	≡69.6	-67.3
0≡4.416 MHz	19.2	≡69.6	-67.3

Figure B≅4 shows the theoretical PSD of 10≡disturber downstream ADSL FEXT on CSA loop #6

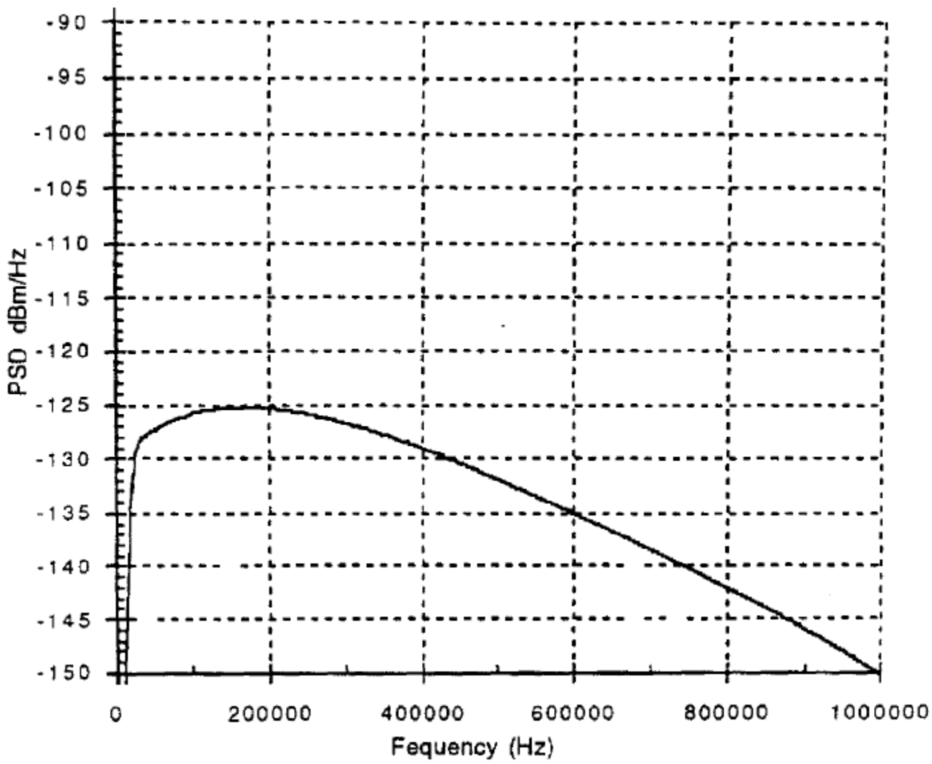


Figure B.4 ≡ Theoretical 10≡disturber ADSL FEXT

B.5 Simulated ADSL≡induced NEXT into the downstream signal

The upstream ADSL signal nominally occupies the band from 25 to 138 kHz, but the upper sidelobes of the pass≡band signal beyond 138 kHz may also contribute to the NEXT into the downstream signal. Their effect will depend on the method of anti≡aliassing used in the remote transmitter, which issue is addressed in 7.12.3. The PSD of the upstream ADSL NEXT can be expressed as:

$$PSD_{\text{ADSL-NEXT}} = PSD_{\text{ADSL,us-Disturber}}\left(x_n f^{\frac{3}{2}}\right), \qquad 0 \le f < \infty$$

where x_{n} is defined in B.1. $PSD_{\text{ADSL,us} \equiv \text{disturber}}$ is difficult to define precisely because of the various sidelobes of the passband signals. For simplicity, the transmit PSD mask given in 7.12 will be used; i.e., ≡38 dBm/Hz from 28 kHz to 138 kHz, ≡62 dBm/Hz at 181.125 kHz, and ≡86 dBm/Hz at 224.25 kHz, with a straight-line fit on a logarithmic scale for the transmit PSDs between 138 kHz and 181.125 kHz, and between 181.125 kHz and 224.25 kHz. This transmit PSD is multiplied by the sinc squared term with f_o = 276 kHz to get the final $PSD_{ADSL,us \equiv disturber}$. In particular, $PSD_{\text{ADSL,us} \equiv \text{disturber}}$ can be expressed as:

$$PSD_{\text{ADSL, us - Disturber}} = K_{mask} \times \frac{\left[\sin\left(\frac{\pi f}{f_o}\right)\right]^2}{\left(\frac{\pi f}{f_o}\right)^2}, \qquad 0 \le f < \infty$$

where $f_o = 276 \times 10^3\ Hz$,

$$K_{mask} = -38\ \text{dBm / Hz} \qquad 28\ \text{kHz} \le f \le 138\ \text{kHz}$$

$$-38 - 24\left(\frac{f - 138000}{43125}\right)\ \text{dBm / Hz} \qquad f > 138\ \text{kHz}$$

Figure B≡5 shows the theoretical PSD of 10≡disturber ADSL NEXT.

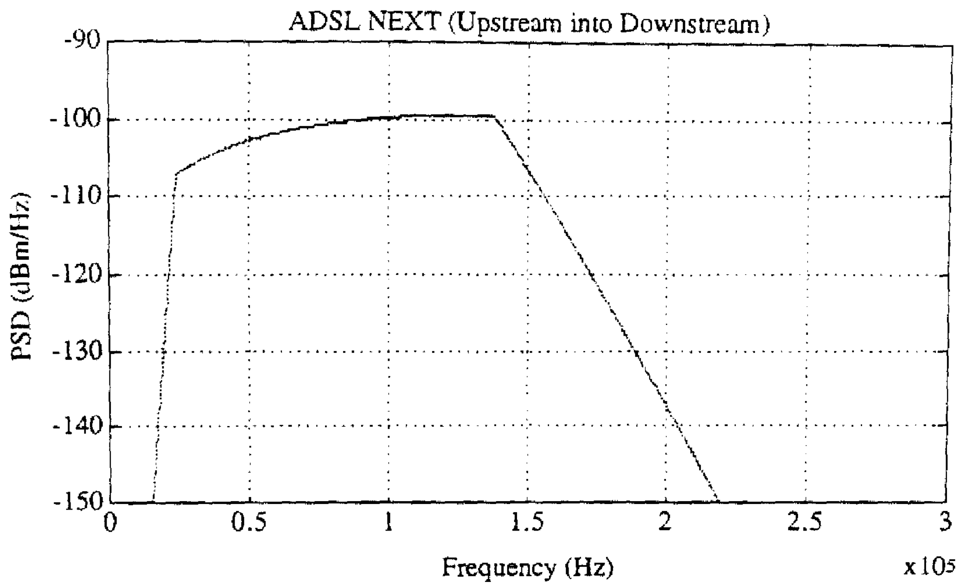


Figure B.5 ≡ Theoretical 10≡disturber ADSL NEXT

Annex C
(normative)

Characteristics of test impulse waveforms

The two test impulse waveforms specified in clause 15 of the standard are described in tables C.1 and C.2 with the impulse wave amplitude given in millivolts at 160 nanosecond time intervals. The specific means of generating these waveforms for test purposes is left to the implementor.

Table C.1 ≅ Impulse number 1

Interval #	Amplitude mV	Interval #	Amplitude m	Interval #	Amplitude mV
1	0.0000	51	≅6.3934	101	0.1598
2	0.0000	52	1.7582	102	≅1.7582
3	0.0000	53	2.2377	103	0.1598
4	0.0000	54	≅4.9549	104	0.4795
5	0.0000	55	2.2377	105	≅1.2787
6	0.0000	56	1.7582	106	0.7992
7	0.0000	57	≅5.5943	107	1.2787
8	0.0000	58	1.4385	108	≅0.7992
9	0.0000	59	2.3975	109	0.0000
10	0.9590	60	≅3.6762	110	≅0.3197
11	≅0.4795	61	1.4385	111	≅2.2377
12	≅1.2787	62	0.4795	112	≅1.1188
13	≅1.1188	63	≅5.7541	113	≅0.7992
14	≅1.4385	64	≅0.4795	114	≅1.5984
15	≅1.5984	65	0.3197	115	0.1598
16	≅2.2377	66	≅3.3566	116	0.4795
17	≅1.4385	67	2.3975	117	≅0.9590
18	7.6721	68	2.3975	118	0.0000
19	6.7131	69	≅3.1967	119	≅0.3197
20	≅16.6229	70	0.7992	120	≅1.5984
21	≅12.9467	71	0.6393	121	0.0000
22	18.7008	72	≅3.5164	122	0.4795
23	9.5902	73	1.1188	123	≅0.7992
24	≅13.5861	74	1.7582	124	0.4795
25	≅5.2746	75	≅2.3975	125	0.7992
26	≅6.3934	76	1.2787	126	≅0.9590
27	≅1.9180	77	0.9590	127	≅0.9590
28	23.0164	78	≅3.3566	128	≅0.4795
29	3.9959	79	0.0000	129	≅0.6393
30	≅23.4959	80	0.1598	130	0.4795
31	≅3.1967	81	≅3.0369	131	1.1188
32	4.3156	82	1.1188	132	0.0000
33	≅3.0369	83	1.5984	133	0.0000
34	10.7090	84	≅2.0779	134	0.0000
35	2.2377	85	0.1598	135	0.0000
36	≅12.9467	86	0.3197	136	0.0000
37	3.1967	87	≅2.5574	137	0.0000
38	1.9180	88	0.1598	138	0.0000
39	≅9.9098	89	0.1598	139	0.0000
40	5.5943	90	≅2.0779	140	0.0000
41	5.9139	91	0.6393		
42	≅6.7131	92	0.9590		
43	2.3975	93	≅1.7582		
44	1.2787	94	≅0.1598		
45	≅8.4713	95	≅0.6393		
46	2.5574	96	≅3.0369		
47	2.8771	97	≅0.3197		
48	≅6.0738	98	0.4795		
49	2.2377	99	≅1.4385		
50	1.7582	100	0.4795		

Table C.2 ≅ Impulse number 2

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
1	0.0000	51	0.6404	101	0.6404
2	0.0000	52	15.5295	102	0.6404
3	0.0000	53	18.8916	103	≅0.4803
4	0.0000	54	≅3.8424	104	≅0.3202
5	0.0000	55	≅3.0419	105	≅0.9606
6	0.0000	56	11.6872	106	≅2.8818
7	0.0000	57	≅0.3202	107	≅2.5616
8	0.0000	58	≅7.5246	108	≅0.8005
9	0.0000	59	13.4483	109	≅0.4803
10	≅0.6404	60	18.4113	110	≅0.8005
11	0.9606	61	≅0.4803	111	≅0.4803
12	0.1601	62	≅3.0419	112	≅0.9606
13	≅5.4433	63	9.7660	113	≅1.1207
14	≅12.3276	64	11.2069	114	≅0.6404
15	≅12.1675	65	4.0025	115	≅0.4803
16	0.0000	66	0.6404	116	≅0.9606
17	5.2832	67	0.6404	117	≅1.4409
18	0.1601	68	1.7611	118	≅1.6010
19	≅20.8128	69	3.3621	119	≅1.2808
20	≅45.3078	70	5.6034	120	≅0.9606
21	≅46.7487	71	7.8448	121	≅0.9606
22	≅28.9778	72	2.5616	122	≅1.2808
23	≅13.4483	73	≅4.6428	123	≅1.1207
24	0.6404	74	0.6404	124	≅1.1207
25	0.9606	75	10.7266	125	≅1.4409
26	≅14.4089	76	8.3251	126	≅1.4409
27	≅13.7685	77	1.9212	127	≅1.4409
28	≅9.4458	78	3.6823	128	≅2.0813
29	≅17.4507	79	4.3227	129	≅2.4015
30	≅2.5616	80	0.3202	130	≅1.9212
31	26.5763	81	2.7217	131	≅1.4409
32	16.1699	82	7.2044	132	≅1.1207
33	≅17.7709	83	3.2020	133	≅1.2808
34	≅17.1305	84	≅2.7217	134	≅1.9212
35	13.6084	85	≅1.4409	135	≅2.2414
36	27.0566	86	1.2808	136	≅2.2414
37	18.0911	87	1.4409	137	≅2.5616
38	14.2488	88	0.8005	138	≅3.0419
39	5.6034	89	0.1601	139	≅3.0419
40	≅8.1650	90	0.0000	140	≅2.5616
41	12.4877	91	1.1207	141	≅1.2808
42	37.3029	92	1.1207	142	≅0.1601
43	9.6059	93	0.6404	143	≅0.6404
44	≅18.8916	94	1.1207	144	≅2.5616
45	5.1231	95	0.6404	145	≅3.2020
46	22.2537	96	≅1.1207	146	≅3.0419
47	1.1207	97	≅0.8005	147	≅2.5616
48	≅0.9606	98	0.1601	148	≅2.0813
49	20.4926	99	≅1.2808	149	≅1.4409
50	14.2488	100	≅1.4409	150	≅1.6010

Table C.2 *(continued)*

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
151	≅1.9212	201	≅0.8005	251	≅1.2808
152	≅1.9212	202	≅0.9606	252	≅1.6010
153	≅2.0813	203	≅1.6010	253	≅1.6010
154	≅2.4015	204	≅2.4015	254	≅1.4409
155	≅2.5616	205	≅2.5616	255	≅0.4803
156	≅2.5616	206	≅2.8818	256	0.4803
157	≅1.9212	207	≅2.7217	257	0.4803
158	≅1.6010	208	≅1.9212	258	≅0.4803
159	≅1.6010	209	≅1.1207	259	≅0.9606
160	≅1.9212	210	≅0.9606	260	≅1.1207
161	≅1.9212	211	≅1.1207	261	≅1.4409
162	≅2.0813	212	≅1.4409	262	≅1.2808
163	≅2.2414	213	≅1.7611	263	≅0.1601
164	≅2.5616	214	≅2.4015	264	0.3202
165	≅2.7217	215	≅2.5616	265	0.0000
166	≅2.2414	216	≅2.2414	266	≅0.4803
167	≅1.2808	217	≅1.7611	267	≅0.4803
168	≅1.2808	218	≅1.7611	268	≅0.4803
169	≅2.2414	219	≅1.4409	269	≅0.6404
170	≅3.0419	220	≅0.9606	270	≅0.4803
171	≅2.8818	221	≅0.8005	271	≅0.1601
172	≅2.5616	222	≅0.9606	272	0.0000
173	≅2.2414	223	≅1.6010	273	0.0000
174	≅1.9212	224	≅2.2414	274	≅0.1601
175	≅1.9212	225	≅2.4015	275	≅0.1601
176	≅2.2414	226	≅2.2414	276	≅0.4803
177	≅2.5616	227	≅1.9212	277	≅0.6404
178	≅2.7217	228	≅1.4409	278	≅0.3202
179	≅2.5616	229	≅0.4803	279	0.1601
180	≅2.4015	230	0.0000	280	0.4803
181	≅2.2414	231	≅0.6404	281	0.3202
182	≅2.0813	232	≅1.6010	282	≅0.1601
183	≅1.7611	233	≅1.7611	283	≅0.3202
184	≅1.6010	234	≅1.6010	284	≅0.4803
185	≅1.7611	235	≅1.9212	285	≅0.6404
186	≅2.2414	236	≅1.9212	286	≅0.4803
187	≅3.0419	237	≅1.4409	287	0.1601
188	≅3.2020	238	≅0.4803	288	0.6404
189	≅2.7217	239	0.0000	289	0.6404
190	≅1.9212	240	0.0000	290	0.4803
191	≅1.2808	241	≅0.6404	291	0.0000
192	≅0.9606	242	≅1.6010	292	≅0.6404
193	≅1.1207	243	≅2.4015	293	≅0.6404
194	≅2.0813	244	≅1.9212	294	≅0.4803
195	≅2.8818	245	≅0.9606	295	≅0.1601
196	≅3.0419	246	≅0.4803	296	0.4803
197	≅2.7217	247	≅0.1601	297	0.6404
198	≅2.7217	248	≅0.1601	298	0.4803
199	≅2.0813	249	0.0000	299	0.6404
200	≅1.4409	250	≅0.8005	300	0.4803

Table C.2 *(continued)*

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
301	≅0.1601	351	0.8005	401	0.9606
302	≅0.9606	352	1.4409	402	0.6404
303	≅0.9606	353	1.6010	403	0.4803
304	≅0.1601	354	1.2808	404	0.6404
305	0.6404	355	0.6404	405	0.6404
306	0.8005	356	0.0000	406	0.4803
307	0.8005	357	≅0.4803	407	0.3202
308	0.4803	358	≅0.6404	408	0.1601
309	0.1601	359	0.0000	409	0.3202
310	≅0.1601	360	0.8005	410	0.4803
311	≅0.3202	361	1.4409	411	0.9606
312	≅0.1601	362	1.6010	412	1.2808
313	0.0000	363	1.2808	413	0.9606
314	0.1601	364	0.6404	414	0.1601
315	0.6404	365	0.0000	415	≅0.1601
316	0.8005	366	≅0.4803	416	0.0000
317	0.6404	367	≅0.1601	417	0.4803
318	0.4803	368	0.1601	418	0.8005
319	0.0000	369	0.9606	419	0.6404
320	≅0.4803	370	1.4409	420	0.4803
321	≅0.4803	371	1.6010	421	0.8005
322	0.1601	372	1.1207	422	0.8005
323	0.8005	373	0.3202	423	0.4803
324	0.8005	374	≅0.4803	424	0.1601
325	0.6404	375	≅0.4803	425	0.0000
326	0.1601	376	0.1601	426	0.0000
327	0.4803	377	0.8005	427	0.1601
328	0.4803	378	1.1207	428	0.3202
329	0.3202	379	1.1207	429	0.6404
330	≅0.3202	380	0.9606	430	0.9606
331	≅0.4803	381	0.6404	431	0.8005
332	0.0000	382	0.1601	432	0.3202
333	0.6404	383	0.0000	433	0.1601
334	1.1207	384	0.1601	434	0.0000
335	1.2808	385	0.6404	435	0.1601
336	0.6404	386	1.1207	436	0.1601
337	0.1601	387	0.9606	437	0.1601
338	≅0.1601	388	0.6404	438	0.1601
339	0.0000	389	0.6404	439	0.6404
340	0.0000	390	0.6404	440	1.1207
341	0.1601	391	0.3202	441	0.9606
342	0.3202	392	0.0000	442	0.4803
343	0.8005	393	0.4803	443	0.0000
344	1.2808	394	1.1207	444	≅0.3202
345	1.2808	395	1.1207	445	≅0.3202
346	0.9606	396	0.6404	446	0.0000
347	0.1601	397	0.1601	447	0.1601
348	≅0.8005	398	0.0000	448	0.6404
349	≅0.9606	399	0.1601	449	0.9606
350	≅0.1601	400	0.8005	450	0.8005

Table C.2 *(concluded)*

Interval #	Amplitude mV	Interval #	Amplitude mV	Interval #	Amplitude mV
451	0.6404	461	0.0000	471	0.0000
452	0.0000	462	≅0.9606	472	0.0000
453	≅0.8005	463	≅1.1207	473	0.0000
454	≅0.8005	464	≅0.4803	474	0.0000
455	0.0000	465	0.4803	475	0.0000
456	0.4803	466	1.1207	476	0.0000
457	0.6404	467	1.1207	477	0.0000
458	0.6404	468	0.6404	478	0.0000
459	0.8005	469	0.0000	479	0.0000
460	0.6404	470	0.0000	480	0.0000

Annex D
(normative)
Vendor identification numbers

Sixteen bits (hex coded from 0000 to FFFF) are reserved for vendor identification; these shall be used by the ATU-C in C-MSGS1 (see 12.6.4), and by the ATU-R in R-MSGS1 (see 12.7.6). The numbers (with 0000 and 0001 reserved) were randomly assigned to the thirty-seven initially identified companies as follows:

	Numerical (hexadecimal) order	Alphabetical order for the first 37	
0002	Westell, Inc.	Adtran	0012
0003	ECI Telecom	Alcatel Network System, Inc.	0022
0004	Texas Instruments	Amati Communications Corp.	0006
0005	Intel	Analog Devices	001C
0006	Amati Communcations Corp.	ADC Telecommunications	0014
0007	General Data Communications (GDC) Inc.	AT&T Network Systems	000A
0008	Level One Communications	AT&T - Paradyne	0011
0009	Crystal Semiconductor	AWA	0021
000A	AT&T-Network Systems	Aware, Inc.	000B
000B	Aware, Inc.	Brooktree	000C
000C	Brooktree	Crystal Semiconductor	0009
000D	NEC	DSC	0018
000E	Samsung	ECI Telecom	0003
000F	Northern Telecom, Inc.	Ericsson Systems	001E
0010	PairGain Technologies	Exar Corporation	001A
0011	AT&T-Paradyne	Fujitsu Network Trans. Systems	0026
0012	Adtran	GDC, Inc.	0007
0013	INC	IBM Corp.	0016
0014	ADC Telecommunications	INC	0013
0015	Motorola	Intel	0005
0016	IBM Corp.	Italtel	0024
0017	Newbridge Networks Corp.	Level One Communications	0008
0018	DSC	Motorola	0015
0019	Teltrend	National Semiconductor	0023
001A	Exar Corp.	NEC	000D
001B	Siemens Stromberg-Carlson	Newbridge Networks Corp.	0017
001C	Analog Devices	Nokia	001D
001D	Nokia	Northern Telecom, Inc.	000F
001E	Ericsson Systems	Orckit Communications, Ltd.	0020
001F	Tellabs Operations, Inc.	PairGain Technologies	0010
0020	Orckit Communications, Inc.	Samsung	000E
0021	AWA	Siemens Stromberg-Carlson	001B
0022	Alcatel Network Systems, Inc.	SAT	0025
0023	National Semiconductor Corp.	Tellabs Operations, Inc.	001F
0024	Italtel	Teltrend	0019
0025	SAT - Société Anonyme de Télécommunications	Texas Instruments	0004
0026	Fujitsu Network Transmission Systems	Westell, Inc.	0002
0027	MITEL	MITEL	0027
0028	Conklin Instrument Corp.	Conklin Instrument Corp.	0028

Annex E
(informative)

Resistance and insertion loss characteristics of typical telephone cables

The tables E.1, E.2, and E.3 provide the calculated resistance and insertion loss between 100 ohm terminations of the loops shown in figure 38.

NOTE - The primary constants of both polyethylene insulated cable (PIC) and pulp insulated cable, at 0° F, 70° F, and 120° F, are specified in Annex G of T1.601-1992.

Table E.1 - Resistance and insertion loss values for test loops at 70^{0} F

Loop #	Resist -ance (ohms)	Insertion loss dB Frequency kHz										
		20	40	100	200	260	300	400	500	600	780	1100
T1.601 # 7	1127	29.8	36.7	45.2	52.8	57.3	60.2	67.7	74.8	81.7	93.0	110
T1.601 # 9	877	27.6	36.4	52.5	47.5	55.7	62.0	60.3	71.5	72.2	82.7	96.2
T1.601 #13	909	26.6	34.1	47.9	48.3	55.7	61.3	62.2	71.4	74.1	85.3	100
CSA # 4	634	17.6	22.0	29.6	39.6	40.1	42.5	49.2	50.2	53.8	55.7	70.7
CSA # 6	751	20.0	24.4	30.1	35.2	38.2	40.2	45.1	49.9	54.4	62.0	73.6
CSA #7	562	17.3	20.9	26.8	39.3	37.8	38.6	43.1	49.9	57.9	60.2	72.7
CSA #8	630	19.2	22.8	27.7	34.4	38.3	40.8	46.9	52.4	57.4	65.4	77.8
Mid-CSA	501	13.3	16.2	20.0	23.4	25.4	26.8	30.1	33.2	36.3	41.3	49.1

Table E.2 - Resistance and insertion loss in dB for test loops 90^0 F

Loop #	Resist -ance (ohms)	Insertion loss dB Frequency kHz										
		20	40	100	200	260	300	400	500	600	780	1100
T1.601 # 7	1176	30.6	37.9	46.9	54.6	59.1	62.1	69.6	76.6	83.4	95.0	113
T1.601 # 9	915	28.4	37.5	53.4	49.1	57.2	63.1	61.9	72.8	73.6	84.2	98.1
T1.601 # 13	948	27.4	35.2	49.0	49.9	57.2	62.5	63.7	72.8	75.6	87.0	102
CSA # 4	658	18.0	22.6	30.4	40.3	41.0	43.5	50.0	50.9	54.3	56.6	71.6
CSA # 6	784	20.5	25.2	31.2	36.4	39.4	41.4	46.4	51.1	55.6	63.3	75.2
CSA # 7	586	17.9	21.6	27.7	40.0	38.7	39.5	44.1	50.9	58.8	61.4	74.0
CSA # 8	657	19.8	23.6	28.7	35.4	39.3	41.8	47.9	53.5	58.6	66.8	79.4
Mid-CSA	523	13.8	16.7	20.7	24.2	26.2	27.6	30.9	34.0	37.1	42.2	50.1

Table E.3 - Resistance and insertion loss in dB for test loops 120^0 F

Loop #	Resist -ance (ohms)	Insertion loss dB Frequency kHz										
		20	40	100	200	260	300	400	500	600	780	1100
T1.601 # 7	1250	31.9	39.6	49.4	57.4	61.8	64.8	72.3	79.3	86.1	97.9	116
T1.601 # 9	972	29.5	39.1	54.7	51.5	59.5	65.5	64.1	74.7	75.7	86.4	101
T1.601 # 13	1008	28.5	36.8	50.7	52.3	59.5	64.5	66.0	74.9	77.9	89.4	105
CSA # 4	704	18.9	23.8	32.2	41.9	42.8	45.2	51.5	52.8	56.0	58.7	74.1
CSA # 6	833	21.4	26.3	32.8	38.2	41.2	43.2	48.2	52.9	57.4	65.3	77.5
CSA # 7	623	18.7	22.6	29.1	41.2	40.0	40.9	45.5	52.5	60.2	63.2	76.0
CSA # 8	699	20.7	24.8	30.2	36.7	40.8	43.3	49.4	55.1	60.4	68.8	81.7
Mid-CSA	555	14.4	17.5	21.8	25.5	27.5	28.8	32.1	35.2	38.3	43.5	51.6

Annex F
(informative)

Overvoltage, surge protection, and EMC

This standard describes the electrical characteristics of the ADSL access signals appearing at the NI, and the physical interface between the network and the CI . Phenomena such as lightning and overvoltages due to inductive interference or power crosses lie beyond the scope of this standard. However, these and other topics are discussed in the following readily-available documents.

≡ ANSI/IEEE C62.42-1986, *Guide for the application of gas tube arrester low-voltage surge-protective devices;*

≡ Technical reference TR-EOP-000001, *Lightning, radio frequency and 60-Hz disturbances at the Bell operating company network interface*, Issue 2, Bellcore, Piscataway, N.J., June 1987.

Both the above documents contain useful information on the application of surge arresters and the loop electrical environment.

≡ ANSI/EIA/TIA-571-1991, *Environmental considerations for telephone terminals*. This standard discusses the normal operating environment of the telephone terminal equipment, fire hazards, and protection.

≡ UL 1459, *Standard for telephone equipment*. This standard deals with safety considerations for telephone equipment.

≡ Bodle, D.W. ; Gresh, P.A. *Lightning surges in paired telephone cable facilities*. Bell Syst. Tech. J. 40: 1961 March.

≡ Gresh, P.A. *Physical and transmission characteristics of customer loop plant*. Bell Syst. Tech. J. 48: 1969 December.

≡ Heirman, Donald N. *Time variations and harmonic content of inductive interference in urban/suburban and residential/rural telephone plants*. IEEE, 1976 Annals No. 512C0010.

≡ Carrol, R. L.; Miller, P. S. *Loop transients at the customer station*. Bell Syst. Tech. J. 59(9): 1980 November..

≡ Carrol, R. L. *Loop transients measurements in Cleveland*, South Carolina. Bell Syst. Tech. J. 59(9): 1980 November.

≡ *Measurement of transients at the subscriber termination of a telephone loop*, CCITT, COM V-No. 53 (November 1983)

≡ Batorsky, D. V.; Burke M.E., 1980 *Bell system noise survey of the loop plant*. AT&T Bell Lab. Tech. J. 63(5): 1984 May-June.

≡ Koga, Hiraki; Motomitsu, Tamio *Lightining-induced surges in paired telephone subscriber cable in Japan*. IEEE Trans. Electromag. Comp. EMC-27: 1985 August.

≡ Clarke, Gord; Coleman, Mike. *Study sheds light on overvoltage protection*. Telephony. 1986 November 24.

The power emitted by the ADSL is limited by the requirements in this standard. Notwithstanding any information contained or implied in this standard, it is assumed that the ADSL will comply with applicable FCC requirements on emission of electromagnetic energy. These requirements may

be found in the Title 47, Code of Federal Regulations, Part 15 and Part 68, and other FCC documents.

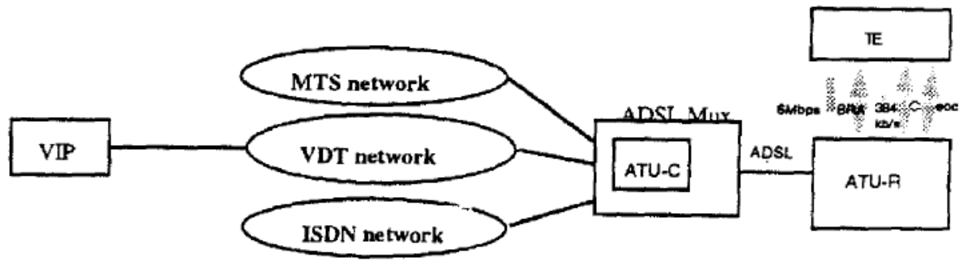
Annex G
(informative)

Examples of ADSL services and applications

G.1 Services and applications

Figure G.1 presents a basic network architecture for ADSL.

The market for ADSL services and applications can be segmented in various ways. Some potential application groups include: *entertainment, educational/institutional, telecommuting, small businesses* and *gaming*.



VDT ≡ Video-dialtone
VIP ≡ Video information Provider

Figure G.1 Basic network architecture for ADSL

ADSL based services can offer users one major new innovation: real-time interactive multimedia services. In addition, the ability to support other application groups is important given that many homes are limited to a single copper pair.

The digital video revolution is opening opportunities for new classes of residential applications. Some of the potential applications can be grouped into the following categories, with examples of each group:

≡ Entertainment:
- ≡ *movies on demand:* end-user dials into a service provider's network to access a listed movie;
- ≡ *music on demand:* end-user dials into a service provider's network to access listed music;
- ≡ *interactive TV:* end-user can access live and/or stored video/graphics, search with the help of pull-down menus, select a channel or channels of choice, and view more than one channel..

≡ Educational/Institutional:
- ≡ *distant class rooms:* end-user can participate in a class remotely and interactively;
- ≡ *on-line books and manuals:* end-user can access books and manuals on-line with the capability to turn pages, go to a certain page, search with key words or subjects, highlight the lines on-line, or make scratch-notes on the side of the book or on a scratchpad;
- ≡ *medical and health consultation:* end-user (hospital, say) can consult with, and transmit medical images to, a doctor at a remote site.

≡ Telecommuting:

≡ *work-at-home:* end-user (an employee, say) can access employer's workstations, printers, facsimile machines on LANs/WANs etc.;
≡ *video-conferencing:* end-user can participate in a video-conference remotely with video in downstream and audio in upstream along with the workstation and screen sharing access.

≡ Small businesses:

≡ *video-conferencing:* similar characteristics as Telecommuting;
≡ *credit-card picture/signature verifications:*small businesses can access a bank's or credit-card company's authorization database, which transmits the card-holder's picture and signature to avoid fraud.

≡ Games:

≡ *interactive games (user-to-server):* end-user is able to play a game interactively from a remote server with various controls;
≡ *interactive games (user-to-user):* one end-user is able to play a game interactively with another distant end-user with various controls;
≡ *off-track betting:* an individual can bet remotely for a live event from home.

G.2 ADSL applications characteristics

For the ADSL services listed in G.1, it is assumed that POTS will always be available with a control channel (C) and asymmetric channel (approximately 1.5, 3 or 6 Mbit/s). User will be able to subscribe to 2B + D and 384 kbit/s services. Some of the characteristics for the above listed services and applications are listed below for information only:

≡ Entertainment:

≡ *movies on demand:*
- high-quality video (N 1.5 Mbit/s) plus audio (N 64 kbit/s) downstream;
- remote control with pause, forward, reverse capability (approx. 100 bits/s) upstream;

≡ *music on demand:*
- high-quality audio (384 kbit/s compressed or 1.5 Mbit/s with 16 bits PCM) downstream;
- remote control with pause, forward, reverse capability (approx. 100 bits/s) upstream;

≡ *interactive TV:*
- high-quality video (N 1.5 Mbit/s) plus normal audio (N 64 kbit/s) downstream;
- mouse or jockey control (N 16 kbit/s) upstream;

≡ Educational/Institutional:

≡ *distant class rooms:*
- high-quality video (> 3 Mbit/s) plus audio (384 kbit/s) downstream;
- audio (384 kbit/s) upstream;

≡ *on-line books and manuals:*
- high-quality video (> 3 Mbit/s) plus data downstream;
- mouse control for pull-down menus (max. of 64 kbit/s) upstream;

≡ *medical and health consultation:*
- high-quality video (> 1.5 Mbit/s) plus voice plus data downstream;
- mouse-like controls to zoom-in and out on the graphical image being transmitted (N 64 kbit/s) upstream;

≅ Telecommuting:
- ≅ *work-at-home:*
  - high-quality video (> 1.5 Mbit/s) plus voice plus data downstream;
  - audio (384 kbit/s) plus data upstream;
- ≅ *video-conferencing:*
  - medium-quality video (N 1.5 Mbit/s) plus graphics plus data plus voice downstream;
  - graphics plus data plus voice (384 kbit/s total) upstream;

≅ Small businesses
- ≅ *screen-sharing:*
  - high-quality graphics (384 kbit/s) plus data plus voice downstream;
  - voice plus graphics (384 kbit/s) plus data upstream;
- ≅ *video-conferencing:*
  - medium-quality video (1.5 Mbit/s) plus graphics plus data plus voice downstream;
  - video (1.5 Mbit/s) plus graphics plus data plus voice upstream;
- ≅ *credit-card picture/signature verifications:*
  - high-quality graphics plusdata plus voice (384 kbit/s for all together) downstream;
  - voice plus graphics plus data (384 kbit/s total) upstream;

≅ Games
- ≅ *interactive games (user-to-server ans user-to-user):*
  - high-speed video (N 3 to 6 Mbit/s) plus audio downstream;
  - speech-recognition, audio, jockey or mouse controls (64 kbit/s) upstream;
- ≅ *off-track betting:*
  - high-quality video (N 3 to 6 Mbit/s) plus audio plus data downstream;
  - audio plus data plus control (16 kbit/s) upstream.

Figure G.2 shows a mapping of downstream and upstream channel capacities with the services that can be supported.

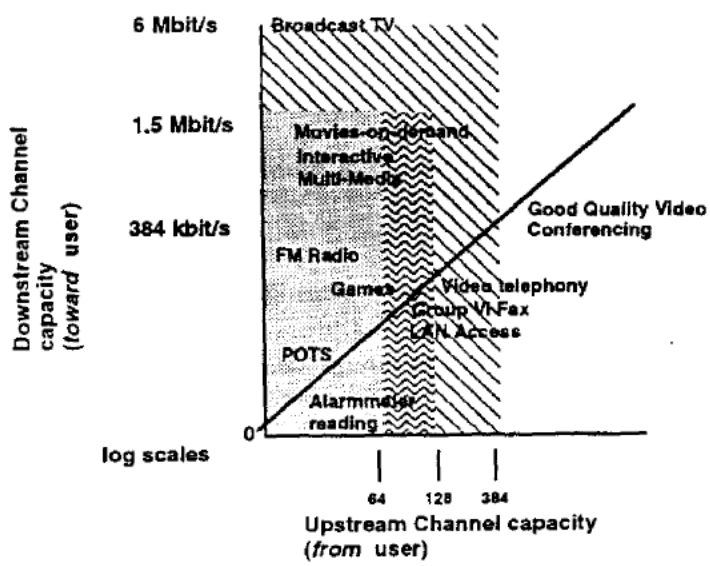


Figure G.2 Applications based on upstream and downstream channel capacity

Annex H
(informative)

Aspects of ADSL systems based on data rates at multiples of 2.048 Mbit/s

H.1 Scope

This annex provides clarification on options within the main body of the standard that relate to systems operating in a 2.048 Mbit/s kbit/s environment (hereafter referred to as 2.048 Mbit/s applications). Note that only transport class 2M-3 is considered here.

H.2 Bearer channel allocations

The transport class and configuration of those allocations that are appropriate for 2048 kbit/s applications are shown in table H.1. The noise models and test loops presented in this annex are for bearer channel allocations as shown in table H.1.

Table H.1 - Bearer channel allocations for 2.048 Mbit/s applications

Transport class 2M-3 configuration	Simplex downstream rate kbit/s	Duplex rate(s) kbit/s
1	2048	160 (Note) 16 (C) (inc. analog POTS)
2	2048	16 (C) (inc. analog POTS)

NOTE This rate is designed to accommodate ISDN-BRA (2B + D + overhead). Some carriers use a concatenated concept of V ref. points (e.g. concatenation of $V_1 + V_5$). Therefore it might be desirable to limit the latency to a value of 1.25 ms per digital section and per ADSL system.

H.3 Noise models

Two noise sources are described for the testing of ADSL systems. These are frequency-domain sources that model the steady-state operating environment caused by crosstalk from adjacent wire pairs due to differing transmission systems. The two models differ because of the need to cater to countries that may or may not have HDB3-based primary rate systems operating at 2048 kbit/s in their access networks. Model A is for the case where no such interferors exist, while model B includes the crosstalk coupling effects of these types of systems.

H.3.1 Injection method

Test noise is applied as described in 15.3.1.1.

H.3.2 Crosstalk noise sources

The power spectral density of the crosstalk noise sources used for performance testing is given in figure H.1 for model A, and in figure H.2 for model B. Model A includes discrete tones, which represent radio frequency interference that is commonly observed, especially on wire pairs routed above ground. Further details of the specification of these noise models are shown in tables G.2 to G.4.

The resulting wideband noise power over the frequency range 1 kHz to 1.5 MHz for model A is ≅ 49.4 0.5 dBm and for model B is ≅43.0 ±0.5 dBm.

The noise probability density function shall be approximately Gaussian with a crest factor N 5.

The accuracy of the power spectral density shall be within 1 dB over the frequency range 1 kHz to 1.5 MHz, when measured with a resolution bandwidth of 1 kHz.

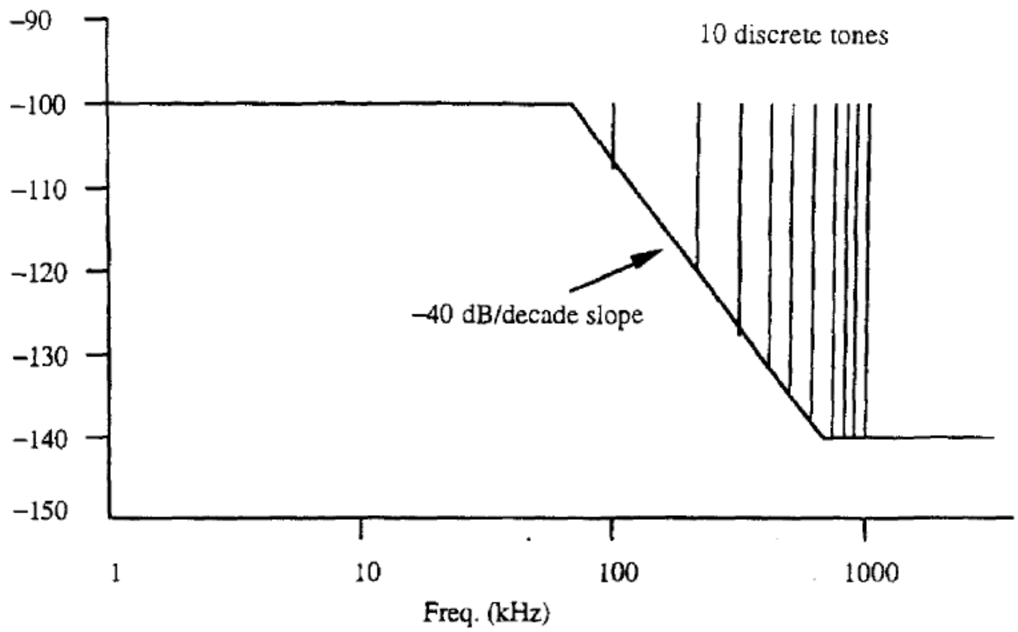


Figure H.1 - Single sided noise power spectral density into 100 W for model A

Table H.2 - Co-ordinates for noise model A

Freq. kHz	PSD dBm/Hz	PSD mV/√Hz
1	-100	3.16
79.5	-100	3.16
795	-140	0.03
1500	-140	0.03

Table H.3 - Tone frequencies and powers for noise model A

Freq. kHz	Power dBm
99	-70
207	-70
333	-70
387	-70
531	-70
603	-70
711	-70
801	-70

909	-70
981	-70

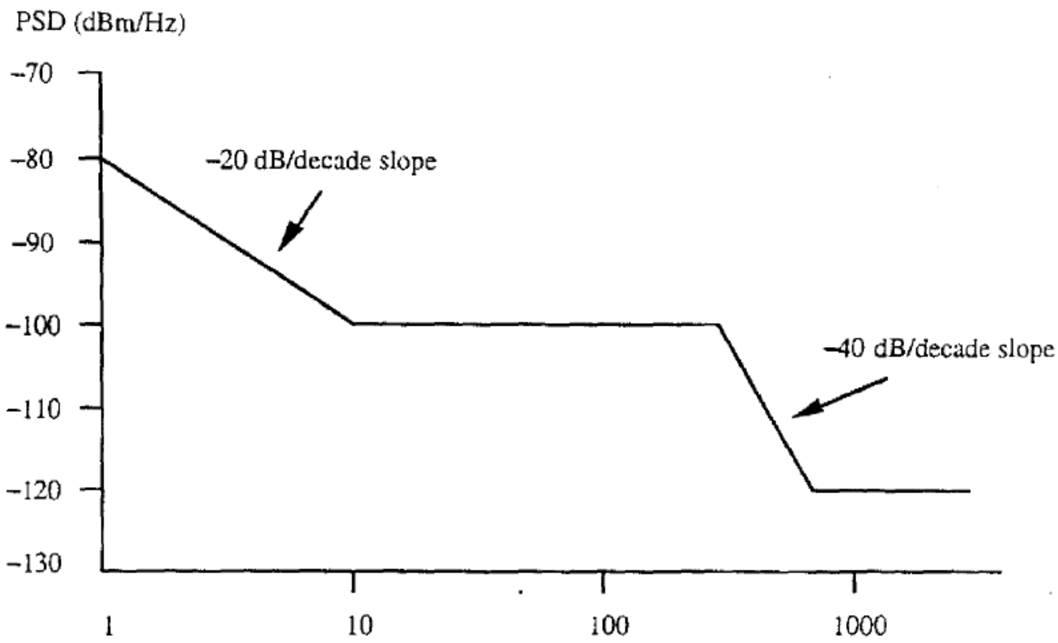


Figure H.2 - Single sided noise power spectral density into 100 W for model B

Table H.4 - Co-ordinates for noise model B

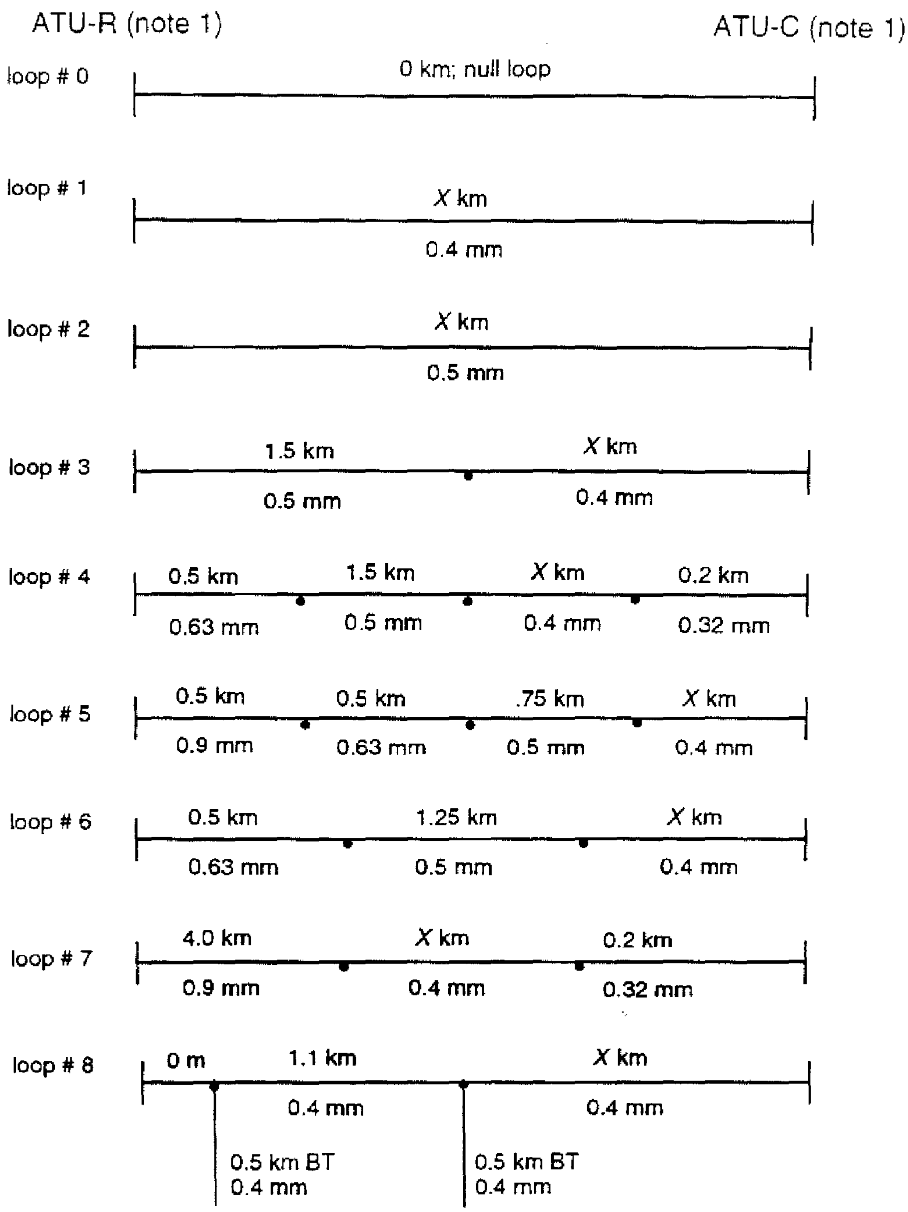
Freq. kHz	**PSD** dBm/Hz	**PSD** mV/∍Hz
1	≅80	31.62
10	≅100	3.16
300	≅100	3.16
711	≅115	0.56
1500	≅115	0.56

H.4 Test loops

To test the performance of the ADSL system incorporating the bearer channel capabilities outlined in clause H.2, the test loops specified in figure H.3 shall be used. The power spectral density of the ADSL downstream transmission shall be as described in 6.13 of the standard with the exception that the power boost option shall not be used for test purposes.

The variation of the primary line constants (R, L and C) with frequency for the different reference cable types are given in tables H.9≅H.13. Note that the capacitance, C, is constant with frequency, and the conductance, G, is assumed zero. The RLC values are quoted per km at a temperature of 20 C and are measured values that have been smoothed.

Note also that there are adjustable sections (marked 'X') in figure H.3. The nominal lengths of these sections, which are are shown in tables H.5 ≅H.8, are calculated from the reference RLC values for each cable type shown in tables H.9 - H.13. For repeatability of measurement results, however, the lengths of these sections shall be adjusted for each individual test loop to give the overall insertion loss shown in tables H.5≅H.8. Insertion loss is measured at 300 kHz with 100 W (balanced resistive) source and termination impedances.



Notes: 1. These test loops are shown with the ATU-Rs on the left; this is in contrast to fig. 38, where the ATU-Rs are on the right.
2. All cable is Polyethylene insulated;
3. 1 km = 3.28 kft;
4. BT = Bridged tap (i.e., section of unterminated cable)

Figure H.3 ≡ Test loop set for transport class 2M≡3 configuration 1 or 2 operation with noise model A or B

Table H.5 ≅ Loop-set insertion loss and nominal lengths for 2M-3 configuration 1 (noise model A)

Loop #	Nominal value of adjustable length 'X' km	Loop insertion loss at 300 kHz dB
1	3.45	49.0
2	4.55	49.0
3	2.30	49.0
4	1.80	49.0
5	2.40	49.0
6	2.25	49.0
7	1.35	49.0
8	1.50	43.0

Table H.6 ≅ Loop-set insertion loss and nominal length for 2M≅3 configuration 2 (noise model A)

Loop #	Nominal value of adjustable length 'X' km	Loop insertion loss at 300 kHz dB
1	3.60	51.0
2	4.80	51.0
3	2.50	51.0
4	2.00	51.0
5	2.55	51.0
6	2.40	51.0
7	1.55	51.0
8	2.10	51.0

Table H.7 ≅ Loop-set insertion loss and nominal lengths for 2M≅3 configuration 1 (noise model B)

Loop #	Nominal value of adjustable length 'X' km	Loop insertion loss at 300 kHz dB
1	2.45	35.0
2	3.20	34.0
3	1.30	35.0
4	0.80	35.0
5	1.40	35.0
6	1.25	35.0
7	0.40	35.0
8	1.00	35.0

Table H.8 ≡ Loop-set insertion loss and nominal lengths for 2M≡3 configuration 2 (noise model B)

Loop #	Nominal value of adjustable length 'X' km	Loop insertion loss at 300 kHz dB
1	2.55	36.0
2	3.40	36.0
3	1.40	36.0
4	0.90	36.0
5	1.50	36.0
6	1.35	36.0
7	0.50	36.0
8	1.10	36.0

Table H.9 ≡ RLC values for 0.32 mm PE cable

C = 40 nF/km and G = 0 at all frequencies

Freq (kHz)	R (/km)	L (mH/km)
0.	409.000	607.639
2.5	409.009	607.639
10.	409.140	607.639
20.	409.557	607.639
30.	410.251	607.639
40.	411.216	607.639
50.	412.447	607.639
100.	422.302	607.631
150.	437.337	607.570
200.	456.086	607.327
250.	477.229	606.639
300.	499.757	605.074
350.	522.967	602.046
400.	546.395	596.934
450.	569.748	589.337
500.	592.843	579.376
550.	615.576	567.822
600.	637.885	555.867
650.	659.743	544.657
700.	681.138	534.942
750.	702.072	526.991
800.	722.556	520.732
850.	742.601	515.919
900.	762.224	512.264
950.	781.442	509.503
1000.	800.272	507.415
1050.	818.731	505.831
1100.	836.837	504.623

Table H.10 ≡ RLC values for 0.4 mm PE cable

C = 50 nF/km and G = 0 at all frequencies

Freq (kHz)	R (/km)	L (mH/km)
0.	280.000	587.132
2.5	280.007	587.075
10.	280.110	586.738
20.	280.440	586.099
30.	280.988	585.322
40.	281.748	584.443
50.	282.718	583.483
100.	290.433	577.878
150.	302.070	571.525
200.	316.393	564.889
250.	332.348	558.233
300.	349.167	551.714
350.	366.345	545.431
400.	383.562	539.437
450.	400.626	533.759
500.	417.427	528.409
550.	433.904	523.385
600.	450.027	518.677
650.	465.785	514.272
700.	481.180	510.153
750.	496.218	506.304
800.	510.912	502.707
850.	525.274	499.343
900.	539.320	496.197
950.	553.064	493.252
1000.	566.521	490.494
1050.	579.705	487.908
1100.	592.628	485.481

Table H.11 ≡ RLC values for 0.5 mm PE cable

C = 50 nF/km and G = 0 at all frequencies

Freq (kHz)	R (/km)	L (mH/km)
0.	179.000	673.574
2.5	179.015	673.466
10.	179.244	672.923
20.	179.970	671.980
30.	181.161	670.896
40.	182.790	669.716
50.	184.822	668.468
100.	199.608	661.677
150.	218.721	654.622
200.	239.132	647.735
250.	259.461	641.208
300.	279.173	635.119
350.	298.103	629.489
400.	316.230	624.309
450.	333.591	619.557
500.	350.243	615.202
550.	366.246	611.211
600.	381.657	607.552
650.	396.528	604.192
700.	410.907	601.104
750.	424.835	598.261
800.	438.348	595.639
850.	451.480	593.217
900.	464.258	590.975
950.	476.710	588.896
1000.	488.857	586.966
1050.	500.720	585.169
1100.	512.317	583.495

Table H.12 ≡ RLC values for 0.63 mm PE cable

C = 45 nF/km and G = 0 at all frequencies

Freq (kHz)	R (/km)	L (mH/km)
0.	113.000	699.258
2.5	113.028	697.943
10.	113.442	693.361
20.	114.737	687.008
30.	116.803	680.714
40.	119.523	674.593
50.	122.768	668.690
100.	143.115	642.718
150.	164.938	622.050
200.	185.689	605.496
250.	204.996	592.048
300.	222.961	580.960
350.	239.764	571.691
400.	255.575	563.845
450.	270.533	557.129
500.	284.753	551.323
550.	298.330	546.260
600.	311.339	541.809
650.	323.844	537.868
700.	335.897	534.358
750.	347.542	531.212
800.	358.819	528.378
850.	369.758	525.813
900.	380.388	523.480
950.	390.734	521.352
1000.	400.816	519.402
1050.	410.654	517.609
1100.	420.264	515.956

Table H.13 ≡ RLC values for 0.9mm PE cable

C = 40 nF/km and G = 0 at all frequencies

Freq (kHz)	R (/km)	L (mH/km)
0.	55.000	750.796
2.5	55.088	745.504
10.	56.361	731.961
20.	59.941	716.775
30.	64.777	703.875
40.	70.127	692.707
50.	75.586	682.914
100.	100.769	647.496
150.	121.866	625.140
200.	140.075	609.652
250.	156.273	598.256
300.	170.987	589.504
350.	184.556	582.563
400.	197.208	576.919
450.	209.104	572.237
500.	220.365	568.287
550.	231.081	564.910
600.	241.326	561.988
650.	251.155	559.435
700.	260.615	557.183
750.	269.745	555.183
800.	278.577	553.394
850.	287.138	551.784
900.	295.452	550.327
950.	303.538	549.002
1000.	311.416	547.793
1050.	319.099	546.683
1100.	326.602	545.663

H.5 ADSL/POTS splitter impedances

The design impedance for the POTS port of the splitter is application specific, and therefore outside the scope of this informative annex. Of particular importance are return loss and resultant sidetone levels. It is expected that some 2048 kbit/s applications will require that the splitter matches to a complex telephony impedance. Significant differences may exist between particular applications; examples are:

≅ telephony impedances;
≅ telephony return loss;
≅ out of (POTS) band signalling systems (e.g., subscriber private metering 11 kHz to 50 kHz);
≅ low frequency telemetry.

H.6 Testing

Performance testing is outlined in the main body of the standard (see clause 15). Note that differences exist here with respect to the crosstalk noise sources (see clause H.3.2) and the test loops (see clause H.4), and the addition of a maximum stress linearity test (see clause H.6.1). Further details appropriate for testing are given in the main body of the standard.

H.6.1 Maximum stress linearity test

This test stresses the ADSL system to ensure that adequate linearity is achieved in implementations. A modified Loop #1 from the loop-set given in figure H.3 is used for this test. The modification is detailed in table H.14. An additive white Gaussian noise source with a power spectral density of ≅140 1 dBm/Hz over the frequency range 1 kHz to 1.5 MHz is applied at the ATU-R in place of the crosstalk source. A resolution bandwidth of 1 kHz is used for calibration of the power spectral density.

Table H.14 ≅ Insertion loss (and nominal length) for Loop #1

Transport class 2M≅3 configuration	Nominal value of adjustable length 'X' of Loop #1 km	Loop insertion loss at 300 kHz dB
1	4.35	62.0
2	4.70	67.0

Annex 1
(informative)

Bibliography

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Bellcore SR-TSZ-002275; *BOC Notes on the LEC Networks-1990*, Issue 2, April 1994.

CCITT Rec. I 610; *B-ISDN Operation and Maintenance Principles and Functions;* June 1992

Annex J
(informative)

Items for further study

The following is a partial list of items in the text of the standard that are indicated as being for further study

≅ the nature of the premises distribution (e.g., bus or star, type of media);

≅ the use of upstream simplex bearer(s) (downstream simplex bearers are already specified);

≅ switching on demand among the configurations allowed by a given transport class and on≅line reassignment of bearer channels;

≅ the entire framed 2.048 Mbit/s (optional) structure is treated as a bearer data stream; the use of a lower payload rate is for further study;

≅ support of the 576 kbit/s optional duplex rate in the default mode of transport classes 2, 3, and 2M≅2;

≅ other uses of the eoc5 bit besides the presently defined ATU≅R "dying gasp";

≅ the use of R≅ACK3;

≅ the effects of the POTS splitter on voice≅band performance;

≅ other payload data rates;

≅ location of the POTS splitters separate from the ATUs;

≅ on≅line change of data rates and reconfigurations;

≅ sensitivity of pilot tones to single-frequency interference;

≅ further definition of impulse noise performance requirements;

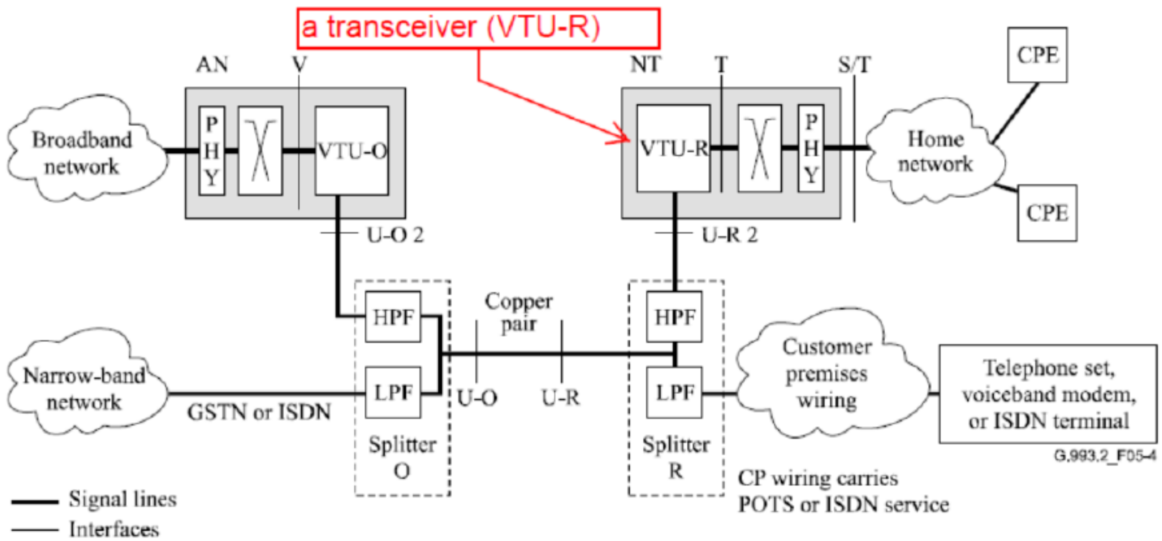
≅ the impact of ADSL signal transfer delay on ISDN transport.

2Wire-Pace 5168NV

([redacted])

US 8,495,473 - VDSL2 - Claim 19

January 30, 2017

US8,495,473 Claim 19	2Wire/Pace 5168NV ([redacted]) - Infringement Support
An apparatus comprising: a multicarrier communications transceiver	**ITU-T G.993.2 VDSL2 Standard** The Accused Products that operate in accordance with the VDSL2 standard include a multicarrier communications transceiver. *See, e.g.*, ITU-T G.993.2 (12/2011) at Figure 5-4 – Generic application reference model for remote deployment with splitter and § 10.4.3 *Modulation by the inverse discrete Fourier transform (IDFT)*:  **Figure 5-4 – Generic application reference model for remote deployment with splitter**

	values of sub-carrier spacing are 4.3125 kHz and 8.625 kHz, both with a tolerance of ±50 ppm. Sub-carrier spacing is profile dependent (see Table 6-1). Multicarrier Modulation (Modulation by IDFT) **10.4.3 Modulation by the inverse discrete Fourier transform (IDFT)** The IDFT is used to modulate the output of the symbol encoder onto the DMT sub-carriers. It converts the NSC complex values Z_i (as defined in 10.3.4) generated by the symbol encoder (frequency domain representation) into $2N$ real values x_n ($n = 0, 1, ..., 2N-1$), which is a time domain representation. The conversion shall be performed with a $2N$ point IDFT, with $N-1 \geq MSI$, as: $$x_n = \sum_{i=0}^{2N-1} \exp\left(j \cdot 2 \cdot \pi \cdot \frac{n \cdot i}{2 \cdot N}\right) \cdot Z_i \quad \text{for } n = 0 \text{ to } 2N-1$$ *See also, e.g.*, ITU-T G.993.2 (02/2006) at Figure 5-4/G.993.2 – Generic application reference model for remote deployment with splitter and § 10.4.3 *Modulation by the inverse discrete Fourier transform (IDFT)*.

[redacted]

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[redacted]

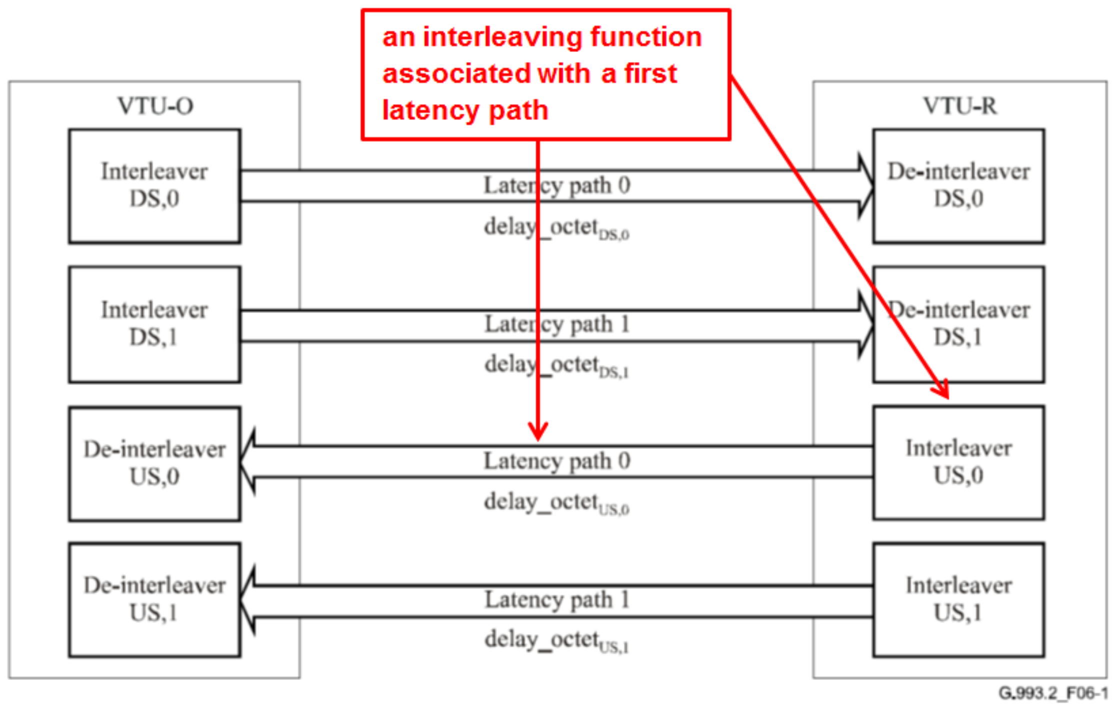
[redacted]

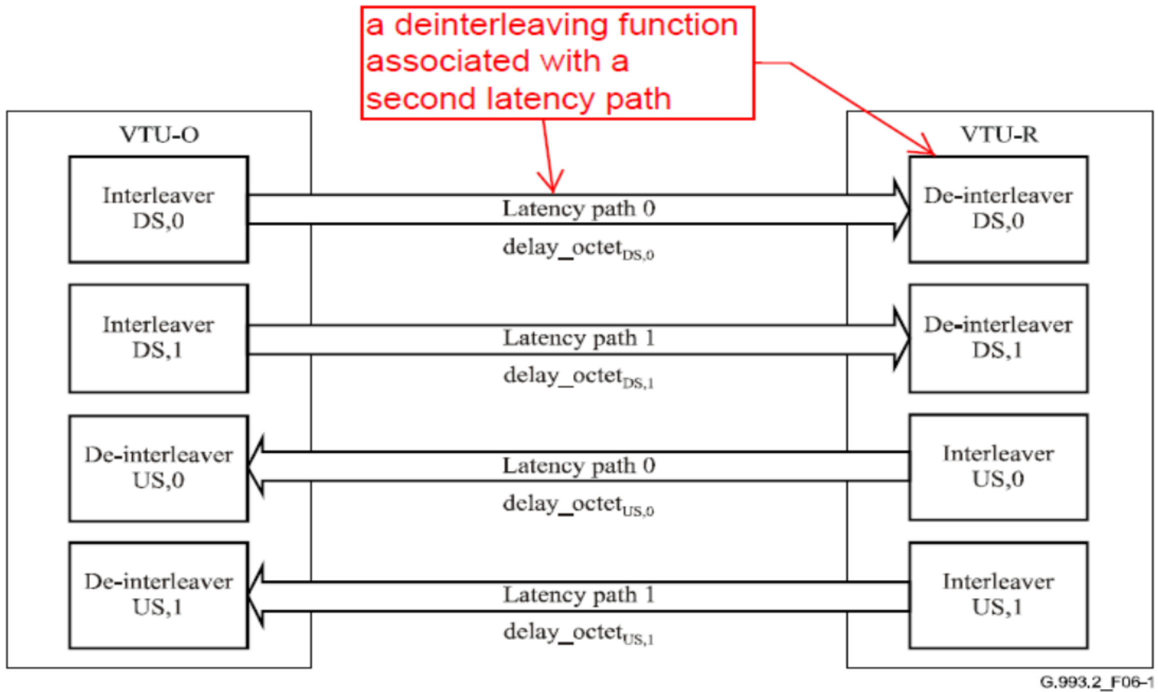
[redacted]

[redacted]

[redacted]

	[redacted]

that is configured to perform an interleaving function associated with a first latency path,	**ITU-T G.993.2 VDSL2 Standard** The Accused Products that operate in accordance with the VDSL2 standard include a multicarrier communications transceiver that is configured to perform an interleaving function associated with a first latency path. *See, e.g.*, ITU-T G.993.2 (12/2011) at Figure 6-1 – Illustration of all latency paths composing the aggregate interleaver and de-interleaver delay specified in each profile:  **Figure 6-1 – Illustration of all latency paths composing the aggregate interleaver and de-interleaver delay specified in each profile** *See also, e.g.*, ITU-T G.993.2 (02/2006) at Figure 6-1/G.993.2 – Illustration of all latency paths composing the aggregate interleaver and de-interleaver delay specified in each profile.

and perform a deinterleaving function associated with a second latency path,	**ITU-T G.993.2 VDSL2 Standard** The Accused Products that operate in accordance with the VDSL2 standard include a multicarrier communications transceiver that is configured to perform a deinterleaving function associated with a second latency path. *See, e.g.*, ITU-T G.993.2 (12/2011) at Figure 6-1 – Illustration of all latency paths composing the aggregate interleaver and de-interleaver delay specified in each profile:  **Figure 6-1 – Illustration of all latency paths composing the aggregate interleaver and de-interleaver delay specified in each profile** *See also, e.g.*, ITU-T G.993.2 (02/2006) at Figure 6-1/G.993.2 – Illustration of all latency paths composing the aggregate interleaver and de-interleaver delay specified in each profile.

the multicarrier communications transceiver being associated with a memory,	**<u>ITU-T G.993.2 VDSL2 Standard</u>** The Accused Products that operate in accordance with the VDSL2 standard include a multicarrier communications transceiver that is associated with a memory. *See, e.g.*, ITU-T G.993.2 (12/2011) at § 6.2.8 *Aggregate interleaver and de-interleaver delay*: **6.2.8 Aggregate interleaver and de-interleaver delay** The required aggregate interleaver and de-interleaver delay is specified in terms of the sum of the end-to-end delays in the upstream and downstream directions over both latency paths, expressed in octets. Therefore, it involves both VTUs. Figure 6-1 illustrates an end-to-end connection with two latency paths and their interleavers and de-interleavers. ****

	The end-to-end delay in octets for the interleaver and de-interleaver pair on path p, with $p = 0, 1$, is given by: $$\text{delay\_octet}_{x,p} = (I_{x,p} - 1) \times (D_{x,p} - 1)$$ where the direction of transmission x is either "DS" for downstream or "US" for upstream, $I_{x,p}$ is the interleaver block length, and $D_{x,p}$ is the interleaver depth. Each interleaver and each de-interleaver for each latency path requires at least (delay_octet$_{x,p}$/2) octets of memory to meet this delay. The actual amount of memory used is implementation specific. Referring to Figure 6-1, the aggregate interleaver and de-interleaver delay is specified as the sum delay_octet$_{DS,0}$ + delay_octet$_{DS,1}$ + delay_octet$_{US,0}$ + delay_octet$_{US,1}$, which can be rewritten as: the transceiver being associated with a memory $$\sum_p (I_{US,p} - 1) \cdot (D_{US,p} - 1) + (I_{DS,p} - 1) \cdot (D_{DS,p} - 1)$$ VTUs shall comply with the requirement $$\sum_p (I_{US,p} - 1) \cdot (D_{US,p} - 1) + (I_{DS,p} - 1) \cdot (D_{DS,p} - 1) \leq \text{MAXDELAYOCTET}$$ where the summation is over all latency paths and MAXDELAYOCTET is the parameter "aggregate interleaver and de-interleaver delay", in octets, specified in Table 6-1 for the profile. The minimum amount of memory required in a transceiver (VTU-O or VTU-R) to meet this requirement is $\frac{\text{MAXDELAYOCTET}}{2}$ octets. The actual amount of memory used is implementation specific. *See also, e.g.*, ITU-T G.993.2 (02/2006) at § 6.2.8 *Aggregate interleaver and de-interleaver delay*.

wherein the memory is allocated[1] between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver and wherein at least a portion of the memory may be allocated to the interleaving function or the deinterleaving function at any one particular time.	**<u>ITU-T G.993.2 VDSL2 Standard</u>** The Accused Products that operate in accordance with the VDSL2 standard include a multicarrier communications transceiver that is associated with a memory, wherein the memory is allocated between the interleaving function and the deinterleaving function in accordance with a message received during an initialization of the transceiver. *See, e.g.*, ITU-T G.993.2 (12/2011) at § 12.3.5.2.1.3 *O-PMS*: **12.3.5.2.1.3 O-PMS** The O-PMS message conveys the initial PMS-TC parameter settings that shall be used in the upstream direction during Showtime. It also specifies the portion of shared interleaver memory that the VTU-R can use to de-interleave the downstream data stream. The full list of parameters carried by the O-PMS message is shown in Table 12-56. **** Field #8 "max_delay_octet$_{DS,0}$" is a 3-byte field that specifies the maximum value of delay_octet$_{DS,0}$ (defined in clause 6.2.8), specified in bytes as an unsigned integer. Field #9 "max_delay_octet$_{DS,1}$" is a 3-byte field that specifies the maximum value of delay_octet$_{DS,1}$ (defined in clause 6.2.8), specified in bytes as an unsigne the special value FFFFFF$_{16}$, the Field #8 (max_delay_o (delay_octet$_{DS,0}$ + delay_octet$_{DS,1}$) and the VTU-R sha octets between both downstream latency paths. The val intends to use interleaver reconfiguration in the downstrea **memory is allocated between the interleaving function and the deinterleaving function in accordance with a message (O-PMS) received during an initialization of the transceiver** Field #10 "max_delay_octet$_{US,0}$" is a 3-byte field that specifies the maximum value of delay_octet$_{US,0}$ (defined in clause 6.2.8), specified in bytes as an unsigned integer. Field #11 "max_delay_octet$_{US,1}$" is a 3-byte field that specifies the maximum value of delay_octet$_{US,1}$ (defined in clause 6.2.8), specified in bytes as an unsigned integer. The values exchanged in Fields #8 to #11 shall be valid during initialization and showtime. In particular, interleaver reconfiguration in a given latency path shall not lead to an interleaver delay that exceeds the values exchanged in O-PMS for that latency path. Any OLR command that results in a delay value that is higher than the one exchange during initialization shall be rejected. *See also, e.g.*, ITU-T G.993.2 (02/2006) at § 12.3.5.2.1.3 *O-PMS*.

[1] The VDSL2 standard does not require that a standard-compliant device actually allocate shared memory as recited in this claim. Rather, the VDSL2 standard requires the message exchange recited in this claim. Thus, all elements of this claim are not required to comply with the VDSL2 standard. However, the portions of the standard recited in this claim chart and, on information and belief, common industry practice make it highly likely that this claim is infringed by the Accused Products.

ITU - Telecommunication Standardization Sector

STUDY GROUP 15

Leuven, 14-18 June, 2004

Temporary Document LB-041

Original: English

Question: 4/15

SOURCE[1]: Infineon Technologies: on behalf of ETSI TM6

TITLE: G.vdsl2: Functional Requirements for VDSL2 from ETSI Network Operators

ABSTRACT

This liaison presents information on functional requirements for VDSL2 from the ETSI TM6 meeting held 7-11 June 2004 in Gent, Belgium.

Dear Mr Stuart,

At our meeting held in Gent from 7 to 11 June 2004 we made some progress on defining the functional requirements for VDSL2. The purpose of this liaison is to make you aware of provisional agreements reached during our meeting and to request that you take these into consideration when defining VDSL2 in ITU-T.

In the table below the TM6 agreements are cross referenced to the G.vdsl2 Issues List.

Item No in ITU-T	Item Description	ETSI TM6 Provisional Agreement.
2.1.2	VDSL2 Deployment scenarios.	VDSL2 shall support at least the following 4 deployment scenarios 1. Fibre to the exchange 2. Fibre to the cabinet 3. Fibre to a remote wire point 4. Fibre to the building.
2.5	Should VDSL2 maintain Annex A, Annex B, Annex C and Annex F band plans?	Annex A (998) and Annex B (997) shall be supported. TM6 is studying the need for additional band plan(s).
2.6 (also 2.11)	Should the frequency band from 25 to 138khz be optional and which direction (upstream/downstream) should it be?	This band shall be mandatory and used for upstream transmission only. The upper frequency of this band shall not exceed 276khz. The first downstream band shall not overlap the U0 band.
2.7.3	Should PSD masks and PBO not be controllable from the CPE?	PSD masks and PBO should not be controllable from the CPE.
3.4	Should a variable	Yes with a maximum frequency of

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	transition frequency between bands U0 and D1 be defined.?	276khz (as done in G992.3 Annex M).
3.4	Should optional overlapped PSDs be defined.	U0 band should not overlap the D1 band.
5	Range and bit rate	See the attached document TM6 WD12. This represents the latest thinking in TM6 with respect to deployment scenarios, rates/reach and noise models. However it is not yet an agreed TM6 position.
8.1	What (downstream and upstream) power cutback mechanisms should VDSL2 support.	Downstream power cutback controlled as in ADSL2 Upstream power cutback is for further study.
8.1, 8.3. 8.8	Should the UPBO method of VDSL1 be used?	Required. Basic mechanism as in VDSL1 but the selection of the reference PSD is still under study.. Parameters of Reference PSD shall be controlled via the MIB. It shall be possible to override the autonomous value for kl0 via the MIB.
11.8	What latency paths should be defined for VDSL2? Should VDSL2 specify dual latency including a slow and a fast path? Each path shall be protected by FEC. The slow path shall include interleaving. The fast path may include interleaving. There shall be at least one of them defined as mandatory	Dual latency is mandatory. Both channels (paths) shall be programmable. Slow 2-TBD ms programmable in approximately 1ms steps. Fast 2-TBD ms. (Note. Interleaver memory could be shared between the two paths and the aggregate delay of the two paths need not exceed 20ms).
11.9	How many bearer channels should be defined fro VDSL2?	The number of bearer channels should equal the number of latency paths .i.e. one bearer per latency path.
13.6.	Shall VDSL2 support ATM,PTM,STM?	VDSL2 shall support ATM and PTM.
13.6.1	Agreed that VDSL2 shall specify at least the following TPS-TCs. ATM based on G.992.3 PTM based on IEEE 802.3ah 64/65 octet encapsulation.	TM6 supports this agreement.

		Additional TM6 provisional agreements for which there is no ITU G.vdsl2 Issues List reference.
Bonding.		Support for bonding required. (max 8 pairs).
Start up.		Use G994.1. Short initialisation <1 sec; full initialisation <10sec. (these target times do not include the time taken for G994.1)
Dynamic rate repartitioning.		Repartitioning between latency paths is required.
Downstream power back off.		Require to allow for a tie cable of up to 200m of 0.5mm cable.

Regards,
Manfred Gindel,
Chairman ETSI TC TM6

Attachment.

WD12r1

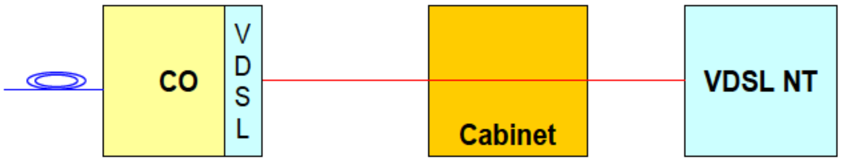
Output from VDSL2 Ad Hoc

Source : John MacDonald, BT plc

Participants : Belgacom, BT, DT, Infineon, KPN, Swisscom, Telia, Telecom Italia

Objective : To agree on a set of standard configurations (or deployment scenarios) that may be used by the European Operators for the deployment of VDSL2 in their respective access networks. Having agreed a set of standard configurations, each was defined in detail. For each deployment scenario, the noise model, expected range and required data rates were then captured.

1) FTTEx
Deployment Scenario :



In this scenario VDSL is deployed from the Central Office (FTTEx).
This VDSL2 profile is applicable to some urban areas where the access network is particularly short. In these areas it could be not convenient to deploy VDSL from a remote point closer to the customers or even forbidden by regulatory rules.

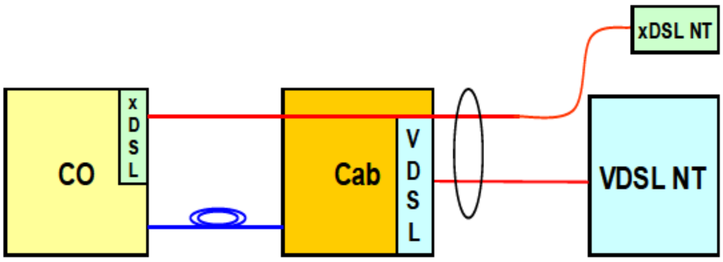
Noise Model : 70 BB systems - 20 VDSL Self FEXT, 18 ADSL FDD over POTS, 7 ADSL over ISDN, 1 x 2 HDSL 2B1Q/2 , 4 SDSL 1024kbit/s , 5 SDSL 2048kbit/s, 14 + 7 ISDN/2B1Q (remember that 7 of these are under ADSL)

Expected range : ≥1400m 0.4mm Cable

Data rate : 15/7 Mbit/s or 20/2 Mbit/s or 10/10 Mbit/s or 6/6 Mbit/s

Note : Assumes US0 used (extended to 276kHz, Annex J/M)

2) FTTCab
Deployment Scenario :



In this scenario both fiber and copper links between the cabinet and the central office are present. VDSL is the only system deployed from the Cabinet; all the legacy systems (SDSL, HDSL, ADSL) deployable from the Central office might be already in place. Therefore, we have to cope with the presence of other xDSL systems terminated at the CO.

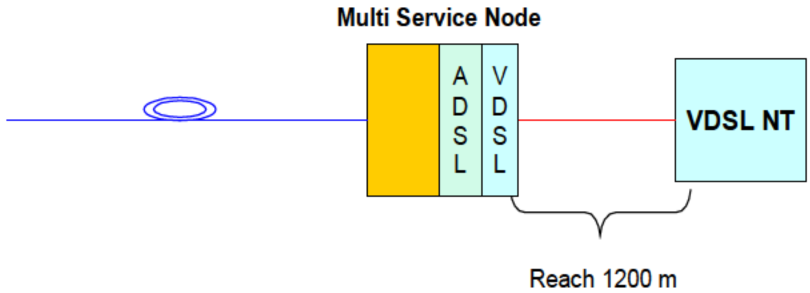
Noise Model : 70 BB systems - 20 VDSL Self FEXT (from cabinet), 18 ADSL over POTS, 7 ADSL FDD over ISDN, 1 x 2 HDSL 2B1Q/2 , 4 SDSL 1024kbit/s , 5 SDSL 2048kbit/s, 14 + 7 ISDN/2B1Q (remember that 7 of these are under ADSL) (from exchange)

Expected range : ≥1000m 0.5mm Cu

Data rate : 15/15 Mbit/s or 10/10 Mbit/s or 12/6 Mbit/s or 20/5 Mbit/s

Note : Assumes that cabinet is 1km (of 0.4mm gauge cable) from exchange

3a) FTTWC
Deployment Scenario :



This scenario is applicable in green field areas, where laying fiber is feasible up to a point quite close to the customers sites and <u>there is no copper plant already in place</u>.
VDSL2 might be not the only xDSL system deployed from the Cabinet: we think that in this scenario, beside VDSL2, deployments of ADLS2 might take place, possibly in one or more of its various annexes.

Noise Model : 20 VDSL Self FEXT, 20 ADSL FDD over ISDN, 2 SDSL 2048Kbit/s, 2 SDSL 1024kbit/s

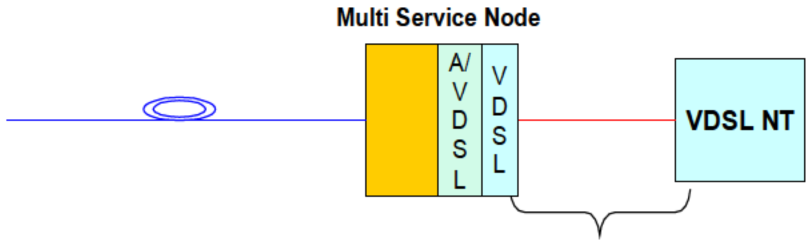
Expected Range : ≥1200m 0.5mm Cu

Data Rate : 10/10Mbit/s

Note : None

3b) FTTWC

Deployment Scenario :



This scenario is applicable in green field areas, where laying fiber is feasible up to a point quite close to the customers sites and there is no copper plant already in place.
VDSL2 might be not the only xDSL system deployed from the Cabinet: we think that in this scenario, beside VDSL2, deployments of ADLS2 might take place, possibly in one or more of its annexes modes; the use of SDSL and other legacy systems will be avoided, as the needs for symmetric services could be covered with VDSL2.

Noise Model : 20 VDSL Self FEXT, 40 ADSL FDD over POTS

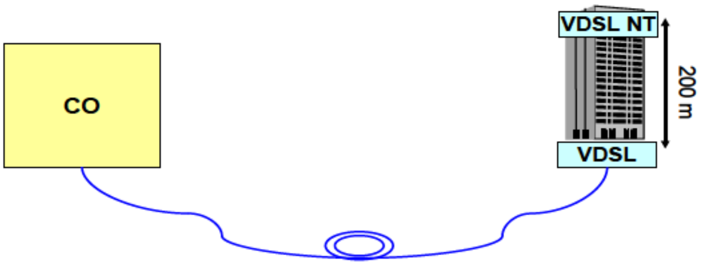
Expected Range : ≥1200m 0.6mm Cu

Data Rate : 15/15Mbit/s, 25/5Mbit/s

Note : None

4a) FTTB

Deployment Scenario :



In this scenario the building is reached only by fibre, so all kinds services are deployed from the distribution point (DP). According to that all the legacy systems, not only xDSL but also POTS and ISDN services, shall migrate on the new infrastructure.

Interoperability with ADSL is a key requirement in this scenario: VDSL systems must interoperate with all the widespread ADSL CPE. Due to the fact that VDSL is the only system deployed from the DP and no other systems are present from remote, there are no particular constraints on the use of particular portions of spectrum (use of frequencies below 1.1 MHz is allowed) and VDSL could exploit maximum level of power.

Noise model : 12 VDSL self FEXT

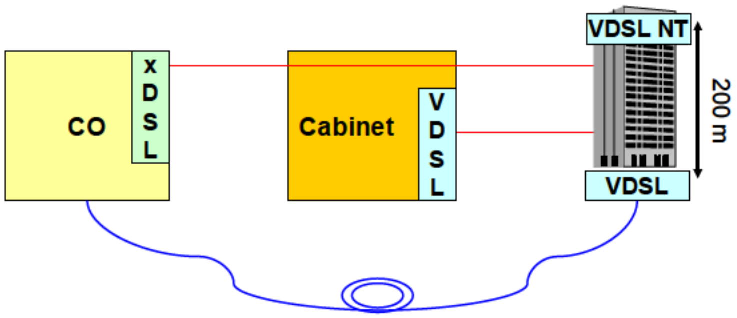
Maximum Range : 200m 0.5mm Cu

Data rate : 10/5Mbit/s, 20/10, 20/20Mbit/s, 60/50Mbit/s

Note : 60/50 data rate assumes extending the VDSL spectrum > 12MHz

4b) FTTB

Deployment Scenario :



In this scenario, the building is served by both the existing copper infrastructure and a fibre overlay. Therefore legacy xDSL systems, like ADSL from CO and/or VDSL from Cabinet, could be in place. In unbundled networks one must take into account that the xDSL systems already in place could belong to other Operators, so the complete migration of the existing broadband services over the new optical platform might be not conceivable, unless the new platform is shared among all the operators (which would make case D1 coincident with case D2).
In this scenario, the copper infrastructure might be used to support legacy services, whose migration on the optical infrastructure is not feasible, and to feed from remote VDSL2 equipment placed in the building.

Noise model : BB systems - 12 VDSL Self FEXT (from basement), 5 ADSL over POTS, 2 ADSL FDD over ISDN, 2 x 2048 SDSL, 2 + 2 ISDN/2B1Q (remember that 2 of these are under ADSL) (from exchange)

Expected Range : 200m 0.5mm Cu

Data rates : 10/5Mbit/s, 20/10, 20/20Mbit/s, 50/50Mbit/s

Note : 60/50 data rate assumes extending the VDSL spectrum > 12MHz

ITU-T

I n t e r n a t i o n a l   T e l e c o m m u n i c a t i o n   U n i o n

ITU-T

TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

G.993.2
(02/2006)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital sections and digital line system – Access networks

Very high speed digital subscriber line transceivers 2 (VDSL2)

ITU-T Recommendation G.993.2

International Telecommunication Union

ITU-T G-SERIES RECOMMENDATIONS

TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

INTERNATIONAL TELEPHONE CONNECTIONS AND CIRCUITS	G.100–G.199
GENERAL CHARACTERISTICS COMMON TO ALL ANALOGUE CARRIER-TRANSMISSION SYSTEMS	G.200–G.299
INDIVIDUAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON METALLIC LINES	G.300–G.399
GENERAL CHARACTERISTICS OF INTERNATIONAL CARRIER TELEPHONE SYSTEMS ON RADIO-RELAY OR SATELLITE LINKS AND INTERCONNECTION WITH METALLIC LINES	G.400–G.449
COORDINATION OF RADIOTELEPHONY AND LINE TELEPHONY	G.450–G.499
TRANSMISSION MEDIA CHARACTERISTICS	G.600–G.699
DIGITAL TERMINAL EQUIPMENTS	G.700–G.799
DIGITAL NETWORKS	G.800–G.899
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General	G.900–G.909
Parameters for optical fibre cable systems	G.910–G.919
Digital sections at hierarchical bit rates based on a bit rate of 2048 kbit/s	G.920–G.929
Digital line transmission systems on cable at non-hierarchical bit rates	G.930–G.939
Digital line systems provided by FDM transmission bearers	G.940–G.949
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Digital section and digital transmission systems for customer access to ISDN	G.960–G.969
Optical fibre submarine cable systems	G.970–G.979
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Access networks	**G.990–G.999**
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TRANSMISSION MEDIA CHARACTERISTICS	G.6000–G.6999
DATA OVER TRANSPORT – GENERIC ASPECTS	G.7000–G.7999
ETHERNET OVER TRANSPORT ASPECTS	G.8000–G.8999
ACCESS NETWORKS	G.9000–G.9999

For further details, please refer to the list of ITU-T Recommendations.

ITU-T Recommendation G.993.2

Very high speed digital subscriber line transceivers 2 (VDSL2)

Summary

This Recommendation is an access technology that exploits the existing infrastructure of copper wires that were originally deployed for POTS services. It can be deployed from central offices, from fibre-fed cabinets located near the customer premises, or within buildings. This Recommendation is an enhancement to ITU-T Rec. G.993.1 [1] that supports asymmetric and symmetric transmission at a bidirectional net data rate up to 200 Mbit/s on twisted pairs using a bandwidth up to 30 MHz.

Source

ITU-T Recommendation G.993.2 was approved on 17 February 2006 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure e.g. interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

INTELLECTUAL PROPERTY RIGHTS

ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

CONTENTS

of the parameter value sent first. For example, a field carrying a 16-bit value $m_{15}, \ldots, m_0$ shall be split into a first byte $B_0=m_{15} \ldots m_8$ and a second byte $B_1=m_7 \ldots m_0$. The description of fields for specific messages is given in detail in 12.3.3, 12.3.4, and 12.3.5. All fields that follow the fields defined for a specific message shall be ignored.

NOTE – If future versions of this Recommendation add extra fields to the ones already defined, for reasons of backward compatibility, these fields must be appended to the currently defined ones.

Some SOC messages may contain several fields. Some fields can be merged together to form a logical entity called a macro-field, such as "PSD descriptor" and "Bands descriptor", which are described in 12.3.3.2.1.1.

12.2.4 SOC idle (O-IDLE, R-IDLE)

When the VTU-O's SOC is in the active state but idle (i.e., it has no message to send), it shall send O-IDLE. Similarly, the VTU-R shall send R-IDLE when its SOC is in the active state but idle.

O-IDLE and R-IDLE shall consist of HDLC flags: $7E_{16}$. This octet shall be sent repeatedly instead of HDLC frames.

12.2.5 SOC messages

12.2.5.1 Message codes

The information payload of every SOC message shall start with a one byte field containing a unique code to identify the type of message. For one-byte messages the message code is the entire content of the message. The message codes for all defined messages are shown in Table 12-2.

NOTE – Other than O/R-REPEAT_REQUEST and O/R-ACK-SEG, which have special message codes, messages sent by the VTU-O have the MSB equal to ZERO, whilst messages sent by the VTU-R have the MSB equal to ONE.

Table 12-2/G.993.2 – Message codes for the SOC messages

SOC message	Message code	Notes
O/R-REPEAT_REQUEST	55_{16}	(Note)
O/R-ACK-SEG	$0F_{16}$	(Note)
VTU-O messages		
O-ACK	00_{16}	(Note)
O-SIGNATURE	01_{16}	see 12.3.3.2.1.1
O-UPDATE	02_{16}	see 12.3.3.2.1.2
O-MSG 1	03_{16}	see 12.3.5.2.1.1
O-PRM	04_{16}	see 12.3.3.2.1.3
O-TA_UPDATE	05_{16}	see 12.3.4.2.1.1
O-TPS	06_{16}	see 12.3.5.2.1.2
O-PMS	07_{16}	see 12.3.5.2.1.3
O-PMD	08_{16}	see 12.3.5.2.1.4
O-PRM-LD	09_{16}	see 12.4.2.1.1
O-MSG-LD	$0A_{16}$	see 12.4.3.1.1

Table 12-2/G.993.2 – Message codes for the SOC messages

SOC message	Message code	Notes
VTU-R messages		
R-ACK	80_{16}	(see Note)
R-MSG 1	81_{16}	see 12.3.3.2.2.1
R-UPDATE	82_{16}	see 12.3.3.2.2.2
R-MSG 2	83_{16}	see 12.3.5.2.2.1
R-PRM	84_{16}	see 12.3.3.2.2.3
R-TA_UPDATE	85_{16}	see 12.3.4.2.2.1
R-TPS-ACK	86_{16}	see 12.3.5.2.2.2
R-PMS	87_{16}	see 12.3.5.2.2.3
R-PMD	88_{16}	see 12.3.5.2.2.4
R-PRM-LD	89_{16}	see 12.4.2.1.2
R-MSG-LD	$8A_{16}$	see 12.4.3.1.2
NOTE – This is the entire payload of the message.		

12.2.5.2 O/R-REPEAT_REQUEST

This message shall be used in RQ mode to request the remote side to resend the last unacknowledged message (segment), as described in 12.2.2.2. The format of the message shall be as specified in 12.2.1, and the payload shall be as specified in Table 12-2.

In AR mode, O/R-REPEAT_REQUEST messages shall be ignored.

12.2.5.3 O/R-ACK-SEG

This message shall be used in RQ mode to acknowledge the reception of intermediate segments of a segmented message, as described in 12.2.2.2. The format of the message shall be as specified in 12.2.1 and the payload shall be as specified in Table 12-2.

In AR mode, and when no segmentation is used, any O/R-ACK-SEG messages shall be ignored.

12.2.5.4 VTU-O and VTU-R messages

These messages are described in detail in 12.3.3, 12.3.4 and 12.3.5.

12.2.6 Segmentation of messages

Messages that are larger than the maximum allowed size (1024 bytes) shall be segmented before transmission; messages shorter than 1024 bytes may also be segmented to improve robustness. To allow segmentation, a segmentation index is included in the control field of the HDLC frame. The four MSBs of this field shall indicate the number of segments, to a maximum of 15, into which the message has been segmented. The four LSBs of this field shall indicate the index of the current segment, starting from 1_{16}. For example, a segmentation index value of 93_{16} indicates the third segment of a total of nine. In case the message is not segmented, the value of the field shall be 11_{16}.

In RQ mode, an acknowledgement (O/R-ACK-SEG) shall be sent for all but the last segment. Typically, the last segment signals the end of the message and will therefore be acknowledged by the reply to the message. The O/R-ACK-SEG message (see Table 12-2) shall be used to acknowledge the reception of the other segments. The O/R-ACK-SEG message shall have its message index assigned by the generic rule defined in 12.2.2.2, and shall be increased by 1 when a new segment is received. The segmentation index of each O/R-ACK-SEG message shall be set

In each bearer channel descriptor, the fields "Minimum net data rate", "Maximum net data rate" and "Reserved net data rate" shall contain the values for net_min_n, net_max_n and $net\_reserve_n$, respectively, selected by the VTU-O. Each shall be coded as an unsigned integer representing the data rate as a multiple of 8 kbit/s.

In the field "Maximum interleaving delay", the parameter $delay\_max_n$ shall be coded as an unsigned integer expressing delay in ms as follows:

- The valid values are $0 \leq delay\_max_n \leq 63$, and $delay\_max_n = 255$.
- The value $delay\_max_n = 1$ is a special value indicating that the interleaver depth D_p shall be set to $D_p = 1$, corresponding to the lowest possible delay.
- The value $delay\_max_n = 0$ is a special value indicating that no bound on the maximum delay is being imposed.
- The value $delay\_max_n = 255$ is a special value indicating an interleaving delay of 1 ms.

The field "Impulse noise protection" shall be coded as follows:

- Bits 0-5 shall contain the required INP_min_n value expressed in DMT symbols.
- The valid values are $0 \leq INP\_min_n \leq 16$.
- The value $INP\_min_n = 0$ is a special value indicating that no minimum level of impulse noise protection is required.
- Bit 6 is reserved and shall be set to ZERO.
- Bit 7: INP_no_erasure_required (see 9.6)
  - When set to ONE, it indicates that the VTU-R receiver shall set $INP_p = INP\_no\_erasure_p$.
  - When set to ZERO, it indicates that the VTU-R receiver is not required to set $INP_p = INP\_no\_erasure_p$.

NOTE – Improper setting of one or more of the following parameters – maximum net data rate, downstream maximum SNR margin, impulse noise protection, maximum interleaving delay (in SNRM_MODE=1), and TXREFVN (in SNRM_MODE=2) – can result in high levels of transmit power that can lead to high crosstalk experienced by DSLs on other pairs in the same binder. Specifically, high values of maximum net data rate, downstream maximum SNR margin, impulse noise protection, low values of maximum interleaving delay (in SNRM_MODE=1), and high values of TXREFVN (in SNRM_MODE=2) are of concern.

The field "TPS-TC options" shall be coded as follows:

- Bit 0: The bit shall be set to ONE to enable pre-emption in this bearer, if and only if the bit was set to ONE for this bearer in both O-MSG 1 and R-MSG 2.
- Bit 1: The bit shall be set to ONE to enable short packets in this bearer, if and only if the bit was set to ONE for this bearer in both O-MSG 1 and R-MSG 2.
- Bits 2-7 are reserved by ITU-T and set to ZERO.

For a bearer mapped to an ATM or STM TPS-TC, the TPS-TC options field is reserved by ITU-T and shall be set to 00_{16}.

12.3.5.2.1.3 O-PMS

The O-PMS message conveys the initial PMS-TC parameter settings that shall be used in the upstream direction during Showtime. It also specifies the portion of shared interleaver memory that the VTU-R can use to de-interleave the downstream data stream. The full list of parameters carried by the O-PMS message is shown in Table 12-46.

Table 12-46/G.993.2 – Description of message O-PMS

	Field name	Format
1	Message descriptor	Message code
2	MSGLP	1 byte
3	Mapping of bearer channels to latency paths	1 byte
4	B_{x0}	1 byte
5	B_{x1}	1 byte
6	LP_0	Latency path descriptor
7	LP_1	Latency path descriptor
8	$MaxD_0$	3 bytes
9	$MaxD_1$	3 bytes

Field #1 "Message descriptor" is a unique one-byte code that identifies the message. See Table 12-2 for a complete list of codes.

Field #2 "MSGLP" is a one-byte field that indicates which latency path is selected for OH frames of Type 1 (which carries message overhead) in the upstream direction. The seven MSBs of the byte shall always be set to ZERO. The LSB shall be set to ZERO to indicate latency path #0 or ONE to indicate latency path #1.

Field #3 "Mapping of bearer channels to latency paths" is a one-byte field that indicates which bearer channels shall be carried in each of the upstream latency paths. The byte is denoted as [cccc dddd]. The bits cccc shall be set to 0000 if bearer channel #0 is to be carried in latency path #0, and to 0001 if bearer channel #0 is to be carried in latency path #1. The bits cccc shall be set to 1111 if the bearer channel #0 is disabled. The bits dddd indicate which latency path carries bearer channel #1 using the same encoding method as used for cccc.

Field #4 "B_{x0}" is a one-byte field that indicates the number of octets from bearer channel #0 that shall be transported in each MDF in the upstream direction. The value shall be either zero or the non-zero value from the set $\{B_{00}, B_{10}\}$.

Field #5 "B_{x1}" is a one-byte field that indicates the number of octets from bearer channel #1 that shall be transported in each MDF in the upstream direction. The value shall be either zero or the non-zero value from the set $\{B_{01}, B_{11}\}$.

Field #6 "LP_0" is a 10-byte field that contains the PMS-TC parameters for latency path #0 in the upstream direction. The "Latency path descriptor" format specified in Table 12-47 shall be used.

Field #7 "LP_1" is a 10-byte field that contains the PMS-TC parameters for latency path #1 in the upstream direction. The "Latency path descriptor" format specified in Table 12-47 shall be used. If latency path #1 is not used, all bytes of LP_1 shall be set to ZERO.

Field #8 "$MaxD_0$" is a 3-byte field that specifies the maximum interleaver delay that the VTU-R shall be allowed to use to de-interleave the data stream in downstream latency path #0. The maximum interleaver delay shall be specified in bytes as an unsigned integer.

Field #9 "$MaxD_1$" is a 3-byte field that specifies the maximum interleaver delay that the VTU-R shall be allowed to use to de-interleave the data stream in downstream latency path #1. The maximum interleaver delay shall be specified in bytes as an unsigned integer. If the value of this field is $FFFFFF_{16}$, the VTU-R shall autonomously partition the interleaver delay specified in Field #8 ($MaxD_0$) between both downstream latency paths.

The latency path descriptor is described in Table 12-47. It contains the primary parameters of the framer, as specified in Table 9-6, and the interleaver settings for one latency path. All values are unsigned integers.

Table 12-47/G.993.2 – Latency path descriptor

Octet	Field	Format	Description
1	T	1 byte	The number of MDFs in an OH sub-frame for the latency path; $T = k \times M$, where k is an integer. The value of T shall not exceed 64.
2	G	1 byte	The total number of overhead octets in an OH sub-frame for the latency path; $1 \le G \le 32$.
3	F	1 byte	Number of OH frames in the OH superframe for the latency path. $1 \le F \le 255$.
4	M	1 byte	The number of MDFs in an RS codeword for the latency path. Only the values 1, 2, 4, 8, 16 are allowable.
5 & 6	L	2 bytes	Contains the value of L for the latency path.
7	R	1 byte	Contains the value of R for the latency path.
8	I	1 byte	Contains the value of I for the latency path.
9 & 10	D	2 bytes	Interleaver depth D for the latency path.

12.3.5.2.1.4 O-PMD

The O-PMD message conveys the initial PMD parameter settings that shall be used in the upstream direction during showtime. The full list of parameters carried by the O-PMD message is shown in Table 12-48.

Table 12-48/G.993.2 – Description of message O-PMD

	Field name	Format
1	Message descriptor	Message code
2	Trellis	1 byte
3	Bits and gains table	$2 \times NSC_{us}$ bytes
4	Tone ordering table	$3 \times \lceil NSC_{us}/2 \rceil$ bytes coded as follows: • Bits 0-11: t_{2n-1} • Bits 12-23: t_{2n}
NOTE – The $\lceil x \rceil$ notation represents rounding to the nearest greater integer.		

Field #1 "Message descriptor" is a unique one-byte code that identifies the message. See Table 12-2 for a complete list of codes.

Field #2 "Trellis" indicates whether trellis coding shall be used in the upstream direction (00_{16} = trellis disabled, 01_{16} = trellis enabled).

Field #3 "Bits and gains table" contains the b_i and g_i values for every sub-carrier in MEDLEYus. The b_i shall indicate the number of bits to be mapped by the VTU-R to the sub-carrier i; the g_i shall indicate the scale factor that shall be applied to sub-carrier i, relative to the gain that was used for that sub-carrier during the transmission of R-P-MEDLEY.

The b_i's and g_i's shall only be defined for sub-carriers from the MEDLEYus set (as indicated in R-PRM), and shall be sent in ascending order of sub-carrier indices i.

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Contents

tion to that in the transmitted signal. The aim of the encoder and decoder is to make the received message resemble, as closely as required, the transmitted message, in spite of the "information" from the noise source.

See also SOURCE CODING THEOREM, CHANNEL CODING THEOREM.

Shannon's theorems *See* SOURCE CODING THEOREM, CHANNEL CODING THEOREM.

shape blending *See* BLENDING.

shared logic system A term sometimes used to refer to a system where several terminals share a CPU simultaneously.

shared memory The use of the same portion of memory by two distinct *processes, or the memory so shared. Shared memory is used for interprocess communication and for purposes, such as common subroutines, that lead to compactness of memory. *See also* MULTIPORT MEMORY, CONCURRENCY.

shareware Software freely distributed with the expectation that anyone wishing to use it on a long-term basis will send a fee to the author. The method of payment and magnitude of the license fee normally forms part of the accompanying documentation. The incentive to register the software may be the promise of future versions, documentation, or extensions to the software.

SHE *Abbrev. for* safety, health, and ergonomics.

sheet feeder A device that may be attached to a printer allowing individual sheets of paper to be fed into the printer without operator action. This device is often available as an add-on feature with impact printers, but is usually incorporated into the mechanism with modern nonimpact printers.

shell A program that provides the *user interface of an *operating system and is often considered to be part of it. The main inner part of the operating system, the *kernel, is thus enclosed by the shell, as in a nut. Some operating systems have a choice of shells.

Shell's method (diminishing increment sort) A sorting algorithm proposed by Donald Shell in 1959 and published as *shellsort*. It is a variant of *straight insertion sort that allows records to take long leaps rather than move one position at a time. It does this by sorting each group $G^{(i)}_j$ of records a distance h_i apart within the file. (The $G^{(i)}_j$ are *disjoint and together contain all the information in the file.) This is repeated for a decreasing sequence of values h_i, and consequently increasing number of groups $G^{(i)}_j$, finally ending with $h_t = 1$.

shellsort *See* SHELL'S METHOD.

shielded twisted pair (STP) *See* TWISTED PAIR.

shift 1. To change the interpretation of characters. The term is commonly met on normal typewriters as a change from lower to upper case.
2. Any complete set of characters obtainable without shifting. Hence *change shift* is a synonym for shift (def. 1).
3. The movement of a bit pattern in a bit string. A *left shift* of m ($<n$) bits will move the bit pattern in a string

$b_1b_2\ldots b_n$

leftward, giving

$b_{m+1}\ldots b_n?\ldots?$

Similarly, a *right shift* of m bits converts

$b_1b_2\ldots b_n$

to $?\ldots?b_1b_2\ldots b_{n-m}$

The bits that are introduced (shown here as question marks) and the use of the bits that are shifted off the end of the string depend on the kind of shift: *arithmetic*, *logical*, or *circular*. In an arithmetic shift the bit strings are regarded as representations of binary integers; if the leading m bits that are lost are all zero, a left shift of m bits is equivalent to multiplication by 2^m and a right shift can be interpreted as integer division by 2^m. In logical shifts the bits introduced are all zero. In circular shifts the bits shifted off at one end are introduced at the other.

shift character Any character used in a stream of characters to change *shift, i.e. to change the interpretation of the characters. *Compare* ESCAPE CHARACTER.

shift counter A *synchronous counter that consists of clocked *flip-flops arranged as a *shift register. Data is propa-

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G.992.1

(06/99)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Digital transmission systems – Digital sections and digital line system – Access networks

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Asymmetric digital subscriber line (ADSL) transceivers

ITU-T Recommendation G.992.1

(Previously CCITT Recommendation)

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For further details, please refer to ITU-T List of Recommendations.

ITU-T RECOMMENDATION G.992.1

ASYMMETRIC DIGITAL SUBSCRIBER LINE (ADSL) TRANSCEIVERS

Summary

This Recommendation describes Asymmetric Digital Subscriber Line (ADSL) Transceivers on a metallic twisted pair that allows high-speed data transmission between the network operator end (ATU-C) and the customer end (ATU-R). This Recommendation provides a variety of bearer channels in conjunction with one of three other services dependent on the environment:

1) ADSL transmission simultaneously on the same pair with voice (band) service;
2) ADSL transmission simultaneously on the same pair with G.961 (Appendix I or II) ISDN services; or
3) ADSL transmission on the same pair with voiceband transmission and with TCM-ISDN (G.961 Appendix III) in an adjacent pair.

Systems allow approximately 6 Mbit/s downstream and approximately 640 kbit/s upstream data rates depending on the deployment and noise environment.

This Recommendation specifies the physical layer characteristics of the Asymmetric Digital Subscriber Line (ADSL) interface to metallic loops.

This Recommendation has been written to help ensure the proper interfacing and interworking of ADSL transmission units at the customer end (ATU-R) and at the network operator end (ATU-C) and also to define the transport capability of the units. Proper operation shall be ensured when these two units are manufactured and provided independently. A single twisted pair of telephone wires is used to connect the ATU-C to the ATU-R. The ADSL transmission units must deal with a variety of wire pair characteristics and typical impairments (e.g. crosstalk and noise).

An ADSL transmission unit can simultaneously convey all of the following: downstream simplex bearers, duplex bearers, a baseband analogue duplex channel, and ADSL line overhead for framing, error control, operations and maintenance. Systems support a minimum of 6.144 Mbit/s downstream and 640 kbit/s upstream.

This Recommendation includes mandatory requirements, recommendations and options; these are designated by the words "shall", "should" and "may" respectively. The word "will" is used only to designate events that take place under some defined set of circumstances.

Two categories of performance are specified. Category I performance is required for compliance with this Recommendation; performance enhancement options are not required for category I equipment. Category II is a higher level of performance (i.e. longer lines and greater impairments). Category II performance and characteristics are not required for compliance with this Recommendation.

This Recommendation defines several optional capabilities and features:

- echo cancellation;
- trellis coded modulation;
- dual latency;
- transport of a network timing reference;
- transport of STM and/or ATM;
- reduced overhead framing modes.

It is the intention of this Recommendation to provide, by negotiation during initialization, for U-interface compatibility and interoperability between transceivers complying to this Recommendation and between transceivers that include different combinations of options.

Source

ITU-T Recommendation G.992.1 was prepared by ITU-T Study Group 15 (1997-2000) and was approved under the WTSC Resolution No. 1 procedure on 22 June 1999.

FOREWORD

ITU (International Telecommunication Union) is the United Nations Specialized Agency in the field of telecommunications. The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of the ITU. The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

INTELLECTUAL PROPERTY RIGHTS

The ITU draws attention to the possibility that the practice or implementation of this Recommendation may involve the use of a claimed Intellectual Property Right. The ITU takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by ITU members or others outside of the Recommendation development process.

As of the date of approval of this Recommendation, the ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementors are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database.

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Recommendation G.992.1

ASYMMETRIC DIGITAL SUBSCRIBER LINE (ADSL) TRANSCEIVERS

(Geneva, 1999)

1 Scope

For interrelationships of this Recommendation with other G.99x-series Recommendations, see Recommendation G.995.1.

This Recommendation describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. The requirements of this Recommendation apply to a single asymmetric digital subscriber line (ADSL).

ADSL provides a variety of bearer channels in conjunction with other services:

- ADSL service on the same pair with voiceband services (including POTS and voiceband data services). The ADSL occupies a frequency band above the voiceband, and is separated from it by filtering;
- ADSL on the same pair as ISDN as defined in Recommendation G.961 Appendices I and II. The ADSL occupies a frequency band above the ISDN, and is separated from it by filtering;
- ADSL service on the same pair with voiceband services (including POTS and voiceband data services), and with ISDN as defined in Recommendation G.961 Appendix III in an adjacent pair.

In the direction from the network operator to the customer premises (i.e. downstream), the bearer channels may consist of full duplex low-speed bearer channels and simplex high-speed bearer channels; in the other direction (i.e. upstream), only low-speed bearer channels are provided.

The transmission system is designed to operate on two-wire twisted metallic cable pairs with mixed gauges. This Recommendation is based on the use of cables without loading coils, but bridged taps are acceptable in all but a few unusual situations.

Specifically, this Recommendation:

- defines the combined options and ranges of the simplex and full-duplex bearer channels provided;
- defines the line code and the spectral composition of the signals transmitted by both ATU-C and ATU-R;
- specifies the transmit signals at both the ATU-C and ATU-R;
- describes the organization of transmitted and received data into frames;
- defines the functions of the operations channel;
- defines the ATU-R to service module(s) interface functions;
- defines the Transmission Convergence Sublayer for ATM transport.

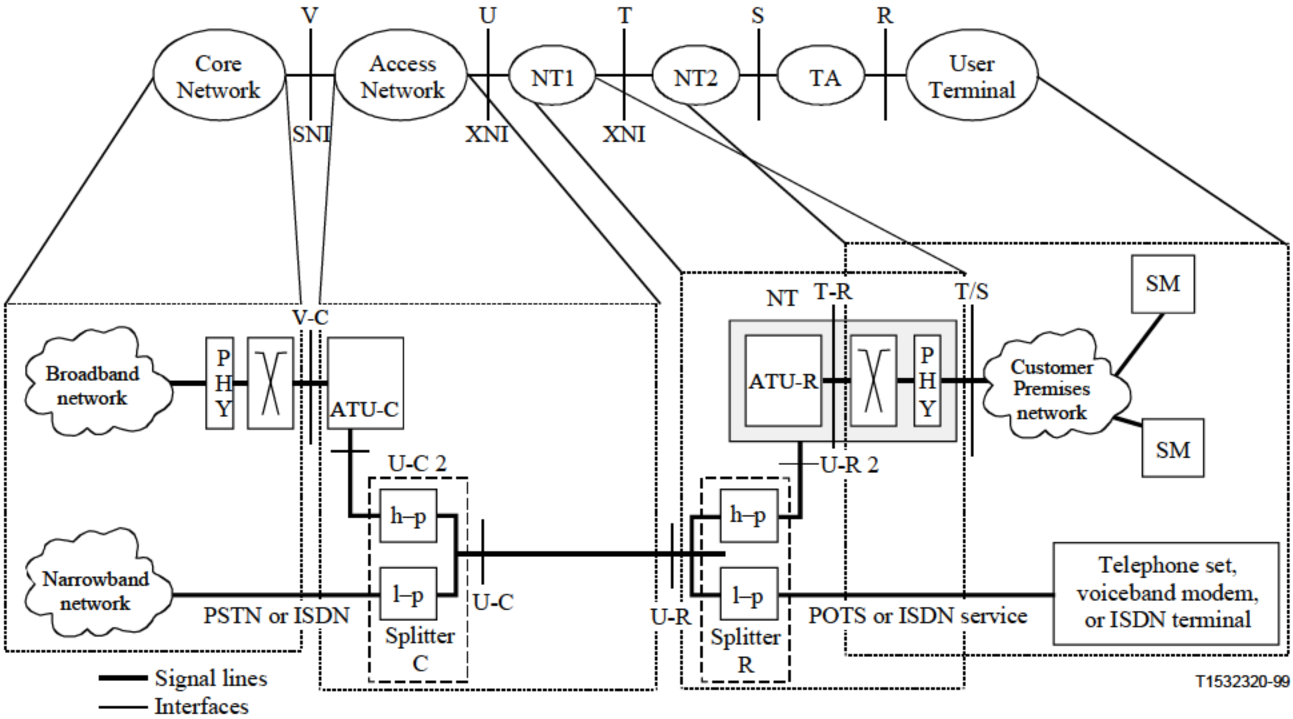
In Annexes A, B and C it also:

- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of voiceband services and both simplex and duplex bearer channels;
- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of ISDN services as defined in Recommendation G.961 Appendices I and II, and both simplex and duplex bearer channels;

- describes the transmission technique used to support the simultaneous transport on a single twisted-pair of voiceband services and both simplex and duplex bearer channels when they are subject to crosstalk from ISDN as defined in Recommendation G.961 Appendix III.

1.1 System reference model

The system reference model shown in Figure 1-1 illustrates the functional blocks required to provide ADSL service.



NOTE 1 – The U-C and U-R interfaces are fully defined in this Recommendation. The V-C and T-R interfaces are defined only in terms of logical functions, not physical. The T/S interface is not defined here.
NOTE 2 – The V-C interface may consist of interface(s) to one or more (STM or ATM) switching systems.
NOTE 3 – Implementation of the V-C and T-R interfaces is optional when interfacing elements are integrated into a common element.
NOTE 4 – One or other of the high-pass filters, which are part of the splitters, may be integrated into the ATU-x; if so, then the U-C 2 and U-R 2 interfaces become the same as the U-C and U-R interfaces, respectively.
NOTE 5 – A digital carrier facility (e.g. SONET extension) may be interposed at the V-C.
NOTE 6 – Due to the asymmetry of the signals on the line, the transmitted signals shall be distinctly specified at the U-R and U-C reference points.
NOTE 7 – The nature of the customer installation distribution and customer premises network (e.g. bus or star, type of media) is for further study.
NOTE 8 – More than one type of T-R interface may be defined, and more than one type of T/S interface may be provided from an ADSL NT (e.g. NT1 or NT2 types of functionalities).
NOTE 9 – A future issue of this Recommendation may deal with customer installation distribution and home network requirements.
NOTE 10 – Specifications for the splitters are given in Annex E.

Figure 1-1/G.992.1 – ADSL system reference model

1.2 Objectives

This Recommendation defines the minimal set of requirements to provide satisfactory simultaneous transmission between the network and the customer interface of a variety of high-speed simplex and low-speed duplex channels and other services such as POTS or ISDN. This Recommendation permits network providers an expanded use of existing copper facilities. All physical layer aspects required to ensure compatibility between equipment in the network and equipment at a remote

location are specified. Equipment may be implemented with additional functions and procedures.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; all users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published.

– ITU-T Recommendation G.961 (1993), *Digital transmission system on metallic local lines for ISDN basic rate access*.

– ITU-T Recommendation G.994.1 (1999), *Handshake procedures for Digital Subscriber Line (DSL) transceivers*.

– ITU-T Recommendation G.996.1 (1999), *Test procedures for Digital Subscriber Line (DSL) transceivers*.

– ITU-T Recommendation G.997.1 (1999), *Physical layer management for Digital Subscriber Line (DSL) transceivers*.

– ITU-T Recommendation I.361 (1999), *B-ISDN ATM layer specification*.

– ITU-T Recommendation I.432.1 (1999), *B-ISDN user-network interface – Physical layer specification*: *General characteristics*.

For Annex B

– ETSI TS 102 080 V1.3.1 (1998), *Transmission and Multiplexing (TM); Integrated Services Digital Network (ISDN) basic rate access; Digital transmission system on metallic local lines*.

For Annex E

– ITU-T Recommendation G.117 (1996), *Transmission aspects of unbalance about earth*.

– ITU-T Recommendation Q.552 (1996), *Transmission characteristics at 2-wire analogue interfaces of digital exchanges*.

– ETSI ETS 300 001 ed.4 (1997), *Attachments to the Public Switched Telephone Network (PSTN); General technical requirements for equipment connected to an analogue subscriber interface in the PSTN*.

3 Definitions

This Recommendation defines the following terms:

3.1 ADSL Lines: See 5.1/G.997.1.

3.2 ADSL system overhead: All overhead needed for system control, including CRC, EOC, AOC synchronization bytes, fixed indicator bits for OAM, and FEC; that is, the difference between total data rate and net data rate.

3.3 aggregate data rate: Data rate transmitted by an ADSL system in any one direction; it includes both net data rate and overhead used by the system for EOC, AOC, CRC check bytes, fixed indicator bits for OAM, synchronization control bytes and capacity for bearer channel synchronization control (i.e. $K_F + K_I$ times 32 kbit/s); it does not include Reed-Solomon FEC redundancy.

3.4 anomalies: An anomaly is a discrepancy between the actual and desired characteristics of an item. The desired characteristics may be expressed in the form of a specification. An anomaly may or may not affect the ability of an item to perform a required function. Performance anomalies are defined in 9.3.1.1 (see Figure 9-4).

3.5 bearer channel: A user data stream of a specified data rate that is transported transparently by an ADSL system.

3.6 bridged taps: Sections of unterminated twisted-pair cables connected in parallel across the cable under consideration.

3.7 category I: Basic category of transceivers with no performance-enhancing options, which meet a basic set of performance requirements.

3.8 category II: Category of transceivers with performance-enhancing options which meet an expanded set of performance requirements.

3.9 channelization: Allocation of the net data rate to bearer channels.

3.10 data frame: A grouping of bytes from fast and interleaved paths over a single symbol time period after addition of FEC bytes and after interleaving (at reference point C of Figure 7-5).

3.11 data symbol rate: The net average rate (after allowing for the overhead of the synchronization symbol) at which symbols carrying user data are transmitted (= 4 kbaud).

3.12 dBrn: Ratio (in decibels) of a power level with respect to a reference power of 1 pico-Watt (equivalent –90 dBm) (reference: Recommendation O.41 – Annex A).

3.13 defects: A defect is a limited interruption in the ability of an item to perform a required function. It may or may not lead to maintenance action depending on the results of additional analysis. Successive anomalies causing a decrease in the ability of an item to perform a required function are considered as a defect (see Figure 9-4).

3.14 DMT symbol: A set of complex values $\{Z_i\}$ forming the frequency domain inputs to the inverse discrete Fourier transform (IDFT) (see 7.11.2). The DMT symbol is equivalently the set of real valued time samples, $\{x_n\}$, related to the set of $\{Z_i\}$ via the IDFT.

3.15 downstream: The transport of data in the ATU-C to ATU-R direction.

3.16 dual latency: Simultaneous transport of multiple data bearer channels in any one direction, in which user data is allocated to both the fast and interleaved paths; that is, $\text{sum}(B_F) > 0$ and $\text{sum}(B_I) > 0$.

3.17 embedded operations channel: A component of ADSL system overhead which provides communications between management entities in the ATU-C and ATU-R. It includes both clear channel and stateful messaging modes.

3.18 far-end: Far-end means performance of the downstream loop-side received signal at the input of the ATU-R, where this performance is reported to the ATU-C in upstream indicators (see Figure 9-4), or performance of the upstream loop-side received signal at the input of the ATU-C, where this performance is reported to the ATU-R in downstream overhead indicators; this case is a mirror image of the above (see Figure 9-4).

3.19 FEC output data frame: The grouping of bytes from fast or interleaved path over a single symbol time period after addition of FEC bytes and before interleaving (at reference point B, Figures 7-8, and 7-9).

3.20 indicator bits: Bits used for OAM purposes; embedded in the synchronization bytes.

3.21 loading coils: Inductors placed in series with the cable at regular intervals in order to improve the voiceband response; removed for DSL use.

3.22 Mux data frame: The grouping of bytes from fast or interleaved path over a single symbol time period before addition of FEC bytes and before interleaving (at reference point A, Figures 7-8 and 7-9).

3.23 near-end: Near-end means performance of the loop-side received signal at the input of the ATU (see Figure 9-4).

3.24 net data rate: Data rate that is available for user data in any one direction; for the downstream direction this is the sum of the net simplex and duplex data rates.

3.25 network timing reference: An 8 kHz timing marker used to support the distribution of a timing reference over the network.

3.26 primitives: Primitives are basic measures of performance, usually obtained from digital signal line codes and frame formats, or as reported in overhead indicators from the far-end. Performance primitives are categorized as events, anomalies and defects. Primitives may also be basic measures of other quantities (e.g. ac or battery power), usually obtained from equipment indicators (see Figure 9-4).

3.27 subcarrier: A particular complex valued input, Z_i, to the IDFT (see 7.11.2).

3.28 showtime: The state of either ATU-C or ATU-R – reached after all initialization and training is completed – in which user data is transmitted.

3.29 single latency: Simultaneous transport of one or more bearer channels in any one direction, in which all user data is allocated to either the fast or the interleaved path; that is, either $\text{sum}(B_F) > 0$ or $\text{sum}(B_I) > 0$.

3.30 splitter: Filter that separates the high frequency signals (ADSL) from the voiceband signals; (frequently called POTS splitter even though the voiceband signals may comprise more than POTS).

3.31 superframe: A grouping of 68 data symbols and one synchronization symbol, over a total time duration of 17 ms (see Figure 7-5).

3.32 symbol rate: The rate at which all symbols, including the synchronization symbol, are transmitted [(69/68)*4.0 = 4.0588 kbaud]; contrasted with the data symbol rate.

3.33 sync byte: An overhead byte present at the beginning of each mux data frame (called "fast" byte in the fast path and "sync" byte in the interleaved path).

3.34 sync frame: A frame with deterministic content sent in the 69th symbol of a superframe (called "synchronization symbol" in Figure 7-5).

3.35 thresholds: See clause 8/G.997.1.

3.36 Threshold Crossing Alert: See Recommendation G.997.1.

3.37 total data rate: Aggregate data rate plus FEC overhead.

3.38 upstream: The transport of data in the ATU-R to ATU-C direction.

3.39 voiceband: 0 to 4 kHz; expanded from the traditional 0.3 to 3.4 kHz to deal with voiceband data services wider than POTS.

3.40 voiceband services: POTS and all data services that use the voiceband or some part of it.

4 Abbreviations

This Recommendation uses the following abbreviations:

ADC	Analogue-to-digital converter
ADSL	Asymmetric digital subscriber line
AEX	A(S) extension byte: byte inserted in the transmitted ADSL frame structure to provide Synchronization capacity that is shared among ASx bearer channels
AFE	Analogue Front End
AGC	Automatic gain control
AOC	ADSL overhead control channel
AS0 to AS3	Downstream simplex bearer channel designators
ASx	Any one of the simplex bearer channels AS0 to AS3
ATM	Asynchronous transfer mode
ATU	ADSL Transceiver Unit
ATU-C	ATU at the central office end (i.e. network operator)
ATU-R	ATU at the remote terminal end (i.e. CP)
ATU-x	Any one of ATU-C or ATU-R
BER	Bit Error Rate
B_F	The number of bytes per frame in a data stream allocated to the fast (i.e. non-interleaved) buffer
B_I	The number of bytes per frame in a data stream allocated to the interleaved buffer
B_i	Number of bits allocated to subcarrier index i
BRA	Basic rate access
C-B&G	Central Office Bits and Gains Information
CI	Customer installation
CLP	Cell Loss Priority
CO	Central office
CP	Customer Premises
CRC	Cyclic Redundancy Check
CRC-8f	Cyclic redundancy check using CRC-8-fast data
CRC-8i	Cyclic redundancy check using CRC-8-interleaved data
CSA	Carrier serving area
DAC	Digital-to-analogue converter
DB	Dual Bitmap (Annex C)
DC	Direct current
DF	Data Frame
DMT	Discrete multitone
DSL	Digital subscriber line
EC	Echo cancelling
EOC	Embedded operations channel (between the ATU-C and ATU-R)
ERL	Echo return loss
ES	Errored second

FDM	Frequency-division multiplexing
FEBE	Far-end Block Error
FEBE-F	Binary indication of far-end block error count-fast data
FEBE-I	Binary indication of far-end block error count-interleaved data
FEC	Forward error correction
FECC-F	Binary indication of forward error correction count-fast data
FECC-I	Binary indication of forward error correction count-interleaved data
FEXT	Far-end crosstalk
FFEC	Far-end Forward Error Correction
FHEC	Far-end Header Error Check
FLCD	Far-end Loss of Cell Delineation
FNCD	Far-end No Cell Delineation
FOCD	Far-end Out of Cell Delineation
GF	Galois Field
GNTPDN	Grant Power Down
GSTN	General switched telephone network
HDSL	High bit rate digital subscriber line
HEC	Header error control
HPF	High pass filter
IB	Indicator Bit
ib0-23	Indicator bits
ID code	Vendor identification code
IDFT	Inverse discrete Fourier transform
ISDN	Integrated Services Digital Network
K_F	Number of bytes in a downstream (or upstream) fast mux data frame
K_I	Number of bytes in a downstream (or upstream) interleaved mux data frame
LCD	Loss of Cell Delineation
LEX	L(S) Extension byte: byte inserted in the transmitted ADSL frame structure to provide synchronization capacity that is shared among LSx and ASx bearer channels
LOF	Loss of frame defect
LOS	Loss-of-signal defect
LPR	Loss-of-power defect
LS0-2	DUPLEX bearer channel designators
LSB	Least significant bit
LSx	Any one of the duplex bearer channels LS0-2
LTR	Local timing reference
MC	Maximum count indication
MSB	Most significant bit
MTPR	Multitone power ratio
NCD	No cell delineation
NEXT	Near-end crosstalk

N_F	Number of bytes in a downstream (or upstream) FEC output-fast data frame
N_I	Number of bytes in a downstream (or upstream) FEC output-interleaved data frame
NI	Network interface
NID	Network interface Device
NMS	Network Management System
n_{PCB}	Power cut-back index (See 10.4.5.1)
NT	Network termination
NTR	Network timing reference: 8 kHz reference to be transmitted downstream
OAM	Operations, administration and maintenance
OCD	Out of Cell Delineation
OSS	Operations Support System
PHY	Physical Layer
PMD/TC	Physical Media Dependent
POTS	Plain old telephone service; one of the services using the voiceband; sometimes used as a descriptor for all voiceband services
ppm	Parts per million
PRBS	Pseudo-random bit sequence
PRD	Pseudo-random downstream sequence
PRU	Pseudo-random upstream sequence
PSD	Power spectral density
PSTN	Public switched telephone network
QAM	Quadrature amplitude modulation
R-B&G	Remote End Bits and Gains Information
RDI	Remote Defect Indication
REJPDN	Reject Power Down
REQPDN	Request Power Down
rfi	Remote failure indication
R_F	Number of downstream (or upstream) FEC redundancy bytes for fast buffer
R_I	Number of downstream (or upstream) FEC redundancy bytes for interleaved buffer
rms	Root mean square
RRSI	Configuration parameters for FEC and interleaving
RS	Reed-Solomon
RT	Remote terminal
SB	Sync Byte
sc0-7	Synchronization control bit(s)
SEF	Severely errored frame
SM	Service module
SNR	Signal-to-Noise Ratio
SONET	Synchronous optical network
SPF	Superframe

SRL	Singing return loss
STM	Synchronous transfer mode
SWB	Sliding Window Buffer (Annex C)
TC	Transmission convergence (sublayer)
TCM	Time Compression Multiplex
T-R	Interface(s) between ATU-R and switching layer (ATM or STM)
T/S	Interface(s) between ADSL network termination and CI or home network
TTR	TCM-ISDN Timing Reference (Annex C)
Tx	Transmitter
U-C	Loop interface-central office end
U-R	Loop interface-remote terminal end
UTC	Unable to comply
V-C	Logical interface between ATU-C and a digital network element such as one or more switching systems
ZHP	Impedance high-pass filter
4-QAM	4-point QAM (i.e. two bits per symbol)
$\oplus$	Exclusive-or; modulo-2 addition

5 Reference Models

Figures 5-1 to 5-4 are not requirements or suggestions for building a DMT transmitter. Rather, they are models for facilitating accurate and concise DMT signal waveform descriptions. In the figures Z_i is DMT subcarrier i (defined in the frequency domain), and x_n is the nth IDFT output sample (defined in the time domain). The DAC and analogue processing block of Figures 5-1 to 5-4 construct the continuous transmit voltage waveform corresponding to the discrete digital input samples. More precise specifications for this analogue block arise indirectly from the analogue transmit signal linearity and power spectral density specifications of 7.13 and 7.14. The use of the figures as a transmitter reference model allows all initialization signal waveforms to be described through the sequence of DMT symbols, $\{Z_i\}$, required to produce that signal. Allowable differences in the characteristics of different digital-to-analogue and analogue processing blocks will produce somewhat different continuous-time voltage waveforms for the same initialization signal. However, a compliant transmitter will produce initialization signals whose underlying DMT subcarrier sequences match exactly those provided in the signal descriptions of 10.4 to 10.9.

5.1 ATU-C transmitter reference models

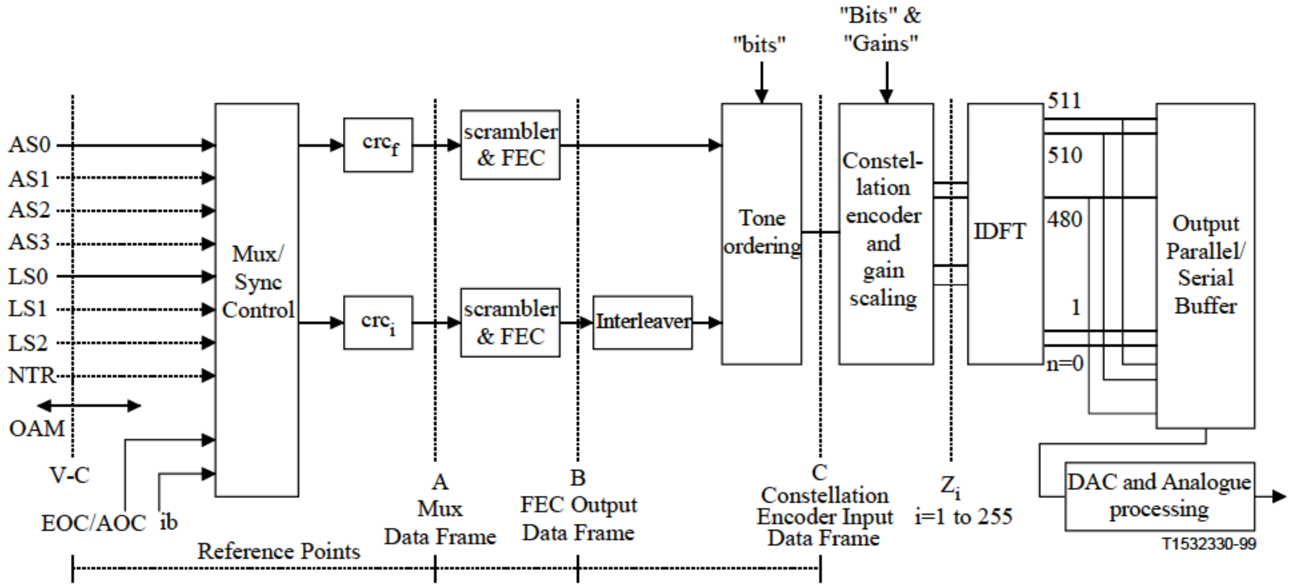
ATM and STM are application options. ATU-C and ATU-R may be configured for either STM bit sync transport or ATM cell transport. Hybrid configurations (i.e. some applications run over ATM, some do not, simultaneously) are outside the scope of this Recommendation.

If the U-C interface is STM bit sync based (i.e. no ATM cells on U-C interface), the ATU-C is configured for STM transport and shall comply to 5.1.1, 6.1 and 7.1. If the U-C interface is ATM cell based (i.e. only ATM cells on U-C interface), the ATU-C is configured for ATM transport and shall comply to 5.1.2, 6.2 and 7.2.

If the U-R interface is STM bit sync based (i.e. no ATM cells on U-R interface), the ATU-R is configured for STM transport and shall comply to 5.2.1, 6.1 and 8.1. If the U-R interface is ATM cell based (i.e. only ATM cells on U-R interface), the ATU-R is configured for ATM transport and shall comply to 5.2.2, 6.2 and 8.2.

5.1.1 ATU-C transmitter reference model for STM transport

Figure 5-1 is a block diagram of an ADSL Transceiver Unit-Central office (ATU-C) transmitter showing the functional blocks and interfaces that are referenced in this Recommendation for the downstream transport of STM data.



NOTE – Solid versus dashed lines are used to indicate required versus optional capabilities respectively. This figure is not intended to be complete in this respect, see clauses 6 and 7 for specific details.

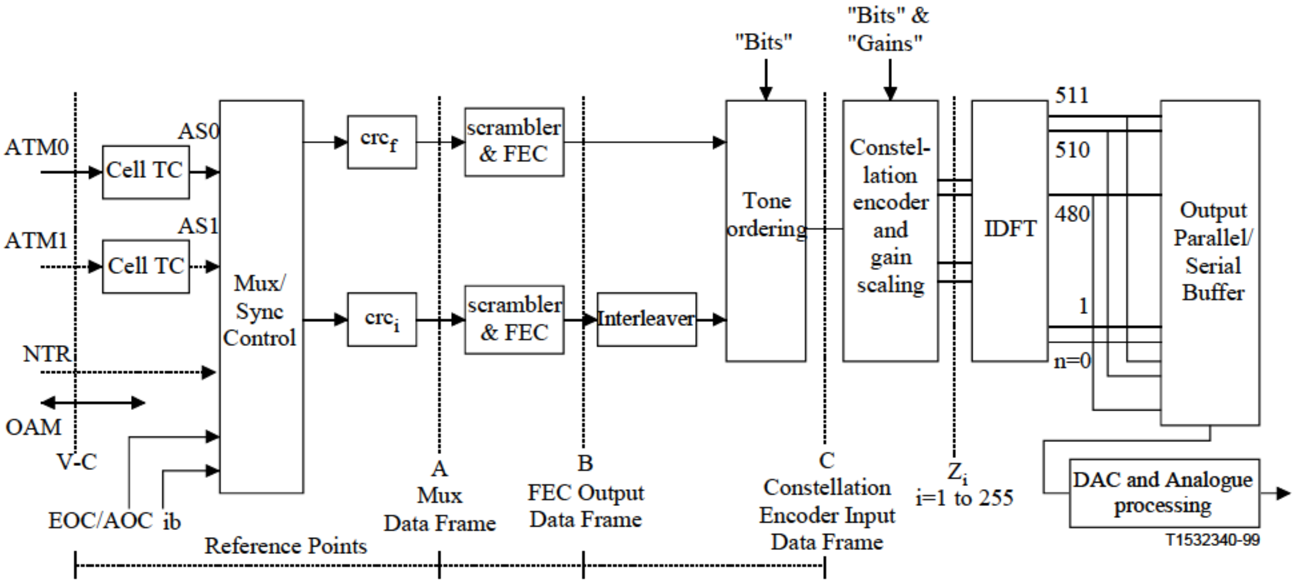
Figure 5-1/G.992.1 – ATU-C transmitter reference model for STM transport

Support of STM is optional; if it is provided, however, the following requirements shall be met:

- The basic STM transport mode is bit serial.
- The framing mode used determines if byte boundaries, if present at the V-C interface, shall be preserved.
- Outside the ASx/LSx serial interfaces data bytes are transmitted MSB first. All serial processing in the ADSL frame (e.g. CRC, scrambling, etc.) shall, however, be performed LSB first, with the outside world MSB considered by the ADSL as LSB. As a result, the first incoming bit (outside world MSB) shall be the first processed bit inside the ADSL (ADSL LSB).
- ADSL equipment shall support at least bearer channels AS0 and LS0 downstream as defined in 6.1. Support of other bearer channels is optional.
- Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the V-C interface to these paths is defined in 7.4. An ADSL system supporting STM shall be capable of operating in a dual latency mode for the downstream direction, in which user data is allocated to both paths (i.e. fast and interleaved), and a single latency mode for both the downstream and upstream directions, in which all user data is allocated to one path (i.e. fast or interleaved). An ADSL system supporting STM transport may be capable of operating in an optional dual latency mode for the upstream, in which user data is allocated to both paths (i.e. fast and interleaved).

5.1.2 ATU-C transmitter reference model for ATM transport

Figure 5-2 is a block diagram of an ADSL Transceiver Unit-Central office (ATU-C) transmitter showing the functional blocks and interfaces that are referenced in this Recommendation for the downstream transport of ATM data.



NOTE – Solid versus dashed lines are used to indicate required versus optional capabilities respectively. This figure is not intended to be complete in this respect, see clauses 6 and 7 for specific details.

Figure 5-2/G.992.1 – ATU-C transmitter reference model for ATM transport

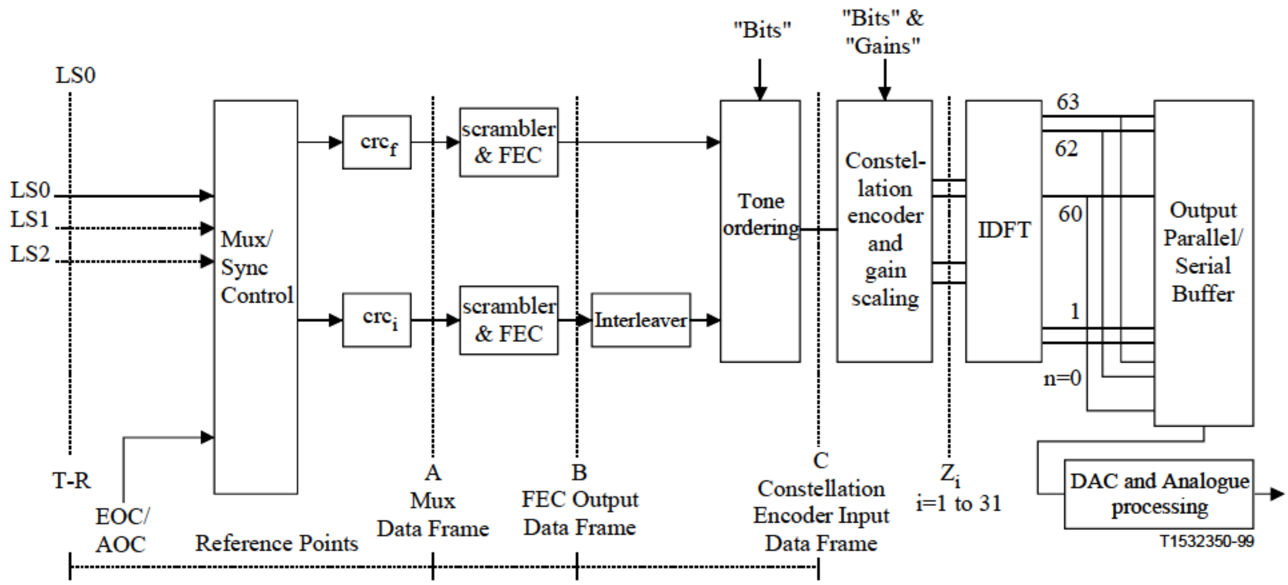
Support of ATM is optional; if it is provided, however, the following requirements shall be met:

- Byte boundaries at the V-C interface shall be preserved in the ADSL data frame.
- Outside the ASx/LSx serial interfaces data bytes are transmitted MSB first. All serial processing in the ADSL frame (e.g. CRC, scrambling, etc.) shall, however, be performed LSB first, with the outside world MSB considered by the ADSL as LSB. As a result, the first incoming bit (outside world MSB) will be the first processed bit inside the ADSL (ADSL LSB), and the CLP bit of the ATM cell header will be carried in the MSB of the ADSL frame byte (i.e. processed last).
- ADSL equipment shall support at least bearer channel AS0 downstream as defined in 6.2. Support of other bearer channels is optional.
- Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the V-C interface to these paths is defined in clause 7. An ADSL system supporting ATM transport shall be capable of operating in a single latency mode, in which all user data is allocated to one path (i.e. fast or interleaved). An ADSL system supporting ATM transport may be capable of operating in an optional dual latency mode, in which user data is allocated to both paths (i.e. fast and interleaved).

5.2 ATU-R transmitter reference models

5.2.1 ATU-R transmitter reference model for STM transport

Figure 5-3 is a block diagram of an ATU-R transmitter showing the functional blocks and interfaces that are referenced in this Recommendation for the upstream transport of STM data.



NOTE – Solid versus dashed lines are used to indicate required versus optional capabilities respectively. This figure is not intended to be complete in this respect, see clauses 6 and 8 for specific details.

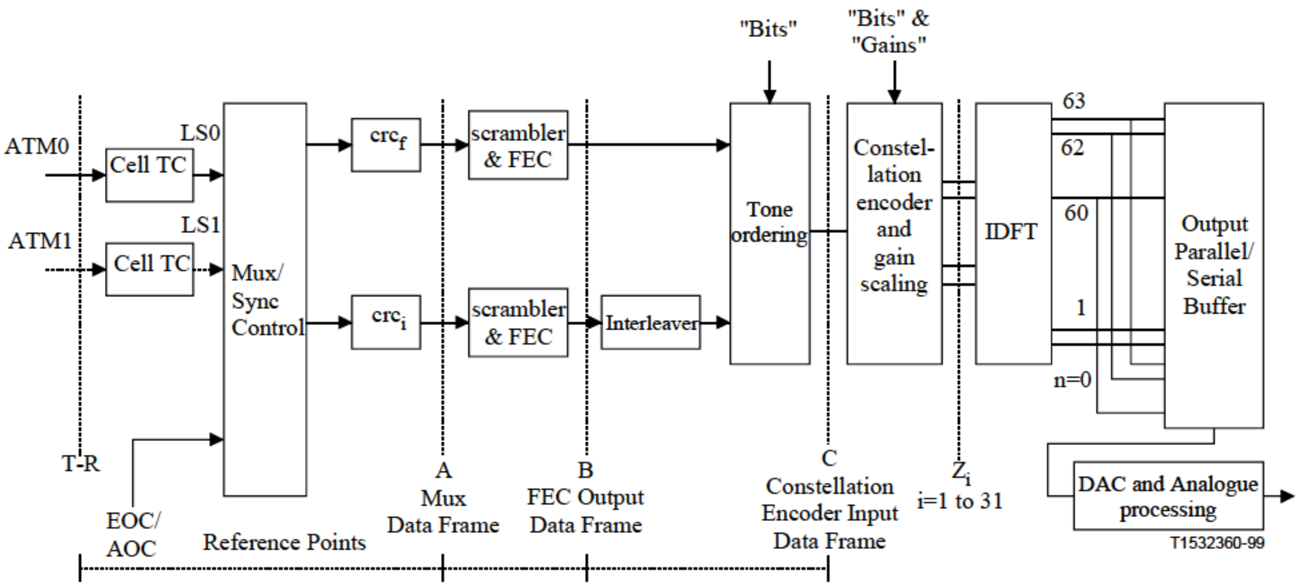
Figure 5-3/G.992.1 – ATU-R transmitter reference model for STM transport

Support of STM is optional; if it is provided, however, the following requirements shall be met:

- The basic STM transport mode is bit serial.
- The framing mode used determines if byte boundaries, if present at the T-R interface, shall be preserved.
- Outside the LSx serial interfaces data bytes are MSB transmitted first. All serial processing in the ADSL frame (e.g. CRC, scrambling, etc.) shall, however, be performed LSB first, with the outside world MSB considered by the ADSL as LSB. As a result, the first incoming bit (outside world MSB) will be the first processed bit inside the ADSL (ADSL LSB).
- ADSL equipment shall support at least bearer channel LS0 upstream as defined in 6.1. Support of other bearer channels is optional.
- Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the T-R interface to these paths is defined in 8.4. An ADSL system supporting STM shall be capable of operating in a dual latency mode for the downstream direction, in which user data is allocated to both paths (i.e. fast and interleaved), and a single latency mode for both the downstream and upstream directions, in which all user data is allocated to one path (i.e. fast or interleaved). An ADSL system supporting STM transport may be capable of operating in an optional dual latency mode for the upstream, in which user data is allocated to both paths (i.e. fast and interleaved).

5.2.2 ATU-R transmitter reference model for ATM transport

Figure 5-4 is a block diagram of an ATU-R transmitter showing the functional blocks and interfaces that are referenced in this Recommendation for the upstream transport of ATM data.



NOTE – Solid versus dashed lines are used to indicate required versus optional capabilities respectively. This figure is not intended to be complete in this respect, see clauses 6 and 8 for specific details.

Figure 5-4/G.992.1 – ATU-R transmitter reference model for ATM transport

Support of ATM is optional; if it is provided, however, the following requirements shall be met:

- Byte boundaries at the T-R interface shall be preserved in the ADSL data frame.
- Outside the LSx serial interfaces data bytes are transmitted MSB first in accordance with Recommendations I.361 and I.432.1. All serial processing in the ADSL frame (e.g. CRC, scrambling, etc.) shall, however, be performed LSB first, with the outside world MSB considered by the ADSL as LSB. As a result, the first incoming bit (outside world MSB) will be the first processed bit inside the ADSL (ADSL LSB), and the CLP bit of the ATM cell header will be carried in the MSB of the ADSL frame byte (i.e. processed last).
- ADSL equipment shall support at least bearer channel LS0 upstream as defined in 6.2. Support of other bearer channels is optional.
- Two paths are shown between the Mux/Sync control and Tone ordering; the "fast" path provides low latency; the interleaved path provides very low error rate and greater latency. The allocation of user data at the T-R interface to these paths is defined in 8.4. An ADSL system supporting ATM transport shall be capable of operating in a single latency mode, in which all user data is allocated to one path (i.e. fast or interleaved). An ADSL system supporting ATM transport may be capable of operating in an optional dual latency mode, in which user data is allocated to both paths (i.e. fast and interleaved).

5.3 ATU-C/R transmitter timing model (Annex C only)

For Annex C, see C.3.3.

6 Transport capacity

An ADSL system may transport up to seven user data streams on seven bearer channels simultaneously:

- up to four independent downstream simplex bearers [unidirectional from the network operator (i.e. V-C interface) to the CI (i.e. T-R interface)];
- up to three duplex bearers (bidirectional between the network operator and the CI).

The three duplex bearers may alternatively be configured as independent unidirectional simplex bearers, and the rates of the bearers in the two directions (network operator toward CI and vice versa) do not need to match.

All bearer channel data rates shall be programmable in any combination of integer multiples of 32 kbit/s. The ADSL data multiplexing format is flexible enough to allow other transport data rates, such as channelizations based on existing 1.544 Mbit/s, but the support of these data rates (non-integer multiples of 32 kbit/s) will be limited by the ADSL system's available capacity for synchronization (see Notes 1 and 2).

The maximum net data rate transport capacity of an ADSL system will depend on the characteristics of the loop on which the system is deployed, and on certain configurable options that affect overhead (see Note 3). The ADSL bearer channel rates shall be configured during the initialization and training procedure.

The transport capacity of an ADSL system per se is defined only as that of the bearer channels. When, however, an ADSL system is installed on a line that also carries POTS or ISDN signals, the overall capacity is that of POTS or ISDN plus ADSL.

A distinction is made between the transport of synchronous (STM) and asynchronous (ATM) data. An ATU-x shall be configured to support STM transmission or ATM transmission. If STM is supported, it shall be as defined in 6.1 and either 7.1 (ATU-C) or 8.1 (ATU-R). If ATM is supported, it shall be as defined in 6.2 and either 7.2 (ATU-C) or 8.2 (ATU-R). Bearer channels configured to transport STM data can also be configured to carry ATM data. ADSL equipment may be capable of simultaneously supporting both ATM and STM transport, but is otherwise outside the scope of this Recommendation.

If an ATU-x supports a particular bearer channel, it shall support it through both the fast and interleaved paths.

In addition, an ADSL system may transport a Network Timing Reference (NTR). The means for doing this are specified in 7.2.4.

NOTE 1 – Part of the ADSL system overhead is shared among the bearer channels for synchronization. The remainder of each channel's data rate that exceeds a multiple of 32 kbit/s is transported in this shared overhead. Only framing mode 0 supports non-integer multiples of 32 kbit/s.

NOTE 2 – The rates for all bearer channels are based on integer multiples of 32 kbit/s. ADSL deployments may, however, need to interwork with DS1 (1.544 Mbit/s) data. The ADSL system overhead and data synchronization (see 6.4.2) provide enough capacity to support the framed DS1 data streams transparently (i.e. the entire DS1 signal is passed through the ADSL transmission path without interpretation or removal of the framing bits and other overhead).

NOTE 3 – One part of the ADSL initialization and training sequence estimates the loop characteristics to determine whether the number of bytes per Discrete MultiTone (DMT) frame required for the requested configuration's aggregate data rate can be transmitted across the given loop. The net data rate is then the aggregate data rate minus ADSL system overhead. Part of the ADSL system overhead is dependent on the configurable options, such as allocation of bearer channels to interleaving or non-interleaving data buffers within the ADSL frame (discussed in 7.4 and 8.4), and part of it is fixed.

NOTE 4 – The latency mode of an ADSL system may be different for downstream and upstream transmission.

6.1 Transport of STM data

ADSL systems transporting STM shall support the simplex bearer channel AS0 and the duplex bearer channel LS0 downstream; support of AS1, AS2, AS3, LS1 and LS2 is optional. Bearer channels AS0, LS0, and any other bearer channels supported shall be independently allocable to a particular latency path as selected by the ATU-C at start-up. The system shall support dual-latency downstream.

ADSL systems transporting STM shall support the duplex bearer channel LS0 upstream using a single latency path; support of LS1 and LS2 and dual latency is optional.

Bearer channel AS0 shall support the transport of data at all integer multiples of 32 kbit/s from 32 kbit/s to 6.144 Mbit/s. Bearer channel LS0 shall support 16 kbit/s and all integer multiples of 32 kbit/s from 32 kbit/s to 640 kbit/s.

When AS1, AS2, AS3, LS1 and LS2 are provided, they shall support the range of integer multiples of 32 kbit/s shown in Table 6-1. Support for integer multiples beyond those required and indicated therein is optional. Further, support for data rates based on non-integer multiples of 32 kbit/s is also optional.

Table 6-1/G.992.1 – Required 32 kbit/s integer multiples for transport of STM

Bearer channel	Lowest Required Integer Multiple	Largest Required Integer Multiple	Corresponding Highest Required Data Rate (kbit/s)
AS0	1	192	6144
AS1	1	144	4608
AS2	1	96	3072
AS3	1	48	1536
LS0	1	20	640
LS1	1	20	640
LS2	1	20	640

Table 6-2 illustrates the data rate terminology and definitions used for STM transport. The reference points refer to those shown in Figures 5-1 through 5-4.

Table 6-2/G.992.1 – Data Rate Terminology for STM transport

Data Rate					Equation (kbit/s)	Reference Point
		STM data rate	=	"Net data rate"	$\Sigma(B_I, B_F) \times 32$ (Note)	ASx + LSx
"Net data rate"	+	Frame overhead rate	=	"Aggregate data rate"	$\Sigma(K_I, K_F) \times 32$	A
"Aggregate data rate"	+	RS Coding overhead rate	=	"Total data rate"	$\Sigma(N_I, N_F) \times 32$	B
"Total data rate"	+	Trellis Coding overhead rate	=	Line rate	$\Sigma\, b_i \times 4$	U
NOTE – Net data rate increase by 16 kbit/s if a 16 kbit/s "C"-channel is used.						

6.2 Transport of ATM data

An ADSL system transporting ATM shall support the single latency mode (Note 1) at all integer multiples of 32 kbit/s up to 6.144 Mbit/s downstream and up to 640 kbit/s upstream. For single latency, ATM data shall be mapped to bearer channel AS0 in the downstream direction and to bearer channel LS0 in the upstream direction. Single latency is defined as all payload data passing through a single latency path. It is important to note that with framing modes 0,1 and 2, overhead data exists in both latency paths even though the payload is allocated to a single latency path.

The need for dual latency for ATM services depends on the service/application profile and is under study. One of three different "latency classes" may be used via:

- single latency, not necessarily the same for each direction of transmission;
- dual latency downstream, single latency upstream;
- dual latency both upstream and downstream.

ADSL systems transporting ATM shall support bearer channel AS0 downstream and bearer channel LS0 upstream, with each of these bearer channels independently allocable to a particular latency path as selected by the ATU-C at start-up. Therefore, support of dual latency is optional for both downstream and upstream.

If downstream ATM data are transmitted through a single latency path (i.e. "fast" only or "interleaved" only), only bearer channel AS0 shall be used, and it shall be allocated to the appropriate latency path. If downstream ATM data are transmitted through both latency paths (i.e. "fast" and "interleaved"), only bearer channels AS0 and AS1 shall be used, and they shall be allocated to different latency paths.

Similarly, if upstream ATM data are transmitted through a single latency path (i.e. "fast" only or "interleaved" only), only bearer channel LS0 shall be used and it shall be allocated to the appropriate latency path. The choice of the fast or interleaved path may be made independently of the choice for the downstream data. If upstream ATM data are transmitted through both latency paths (i.e. "fast" and "interleaved"), only bearer channels LS0 and LS1 shall be used and they shall be allocated to different latency paths.

Bearer channel AS0 shall support the transport of data at all integer multiples of 32 kbit/s from 32 kbit/s to 6.144 Mbit/s. Bearer channel LS0 shall support all integer multiples of 32 kbit/s from 32 kbit/s to 640 kbit/s. Support for data rates based on non-integer multiples of 32 kbit/s is also optional.

When AS1 and LS1 are provided, they shall support the range of integer multiples of 32 kbit/s shown in Table 6-1. Support for integer multiples beyond those required and indicated in Table 6-1 is optional. Further, support for data rates based on non-integer multiples of 32 kbit/s is also optional.

Bearer channels AS2, AS3 and LS2 shall not be provided for an ATM based ATU-x.

NOTE 1 – For ATM systems, the channelization of different payloads is embedded within the ATM data stream using different Virtual Paths and/or Virtual Channels. Therefore the basic requirements for ATM are for only one ADSL bearer channel downstream and only one ADSL bearer channel upstream.

NOTE 2 – More details of the ATM to Physical layer logical interface are given in Appendix I.

Table 6-3 illustrates the data rate terminology and definitions used for ATM transport. The reference points refer to those shown in Figures 5-1 through 5-4.

Table 6-3/G.992.1 – Data rate terminology for ATM transport

Data Rate					Equation (kbit/s)	Reference Point
$53 \times 8 \times$ ATM cell rate			=	"Net data rate"	$\Sigma(B_I, B_F) \times 32$	ASx + LSx
"Net data rate"	+	Frame overhead rate	=	"Aggregate data rate"	$\Sigma(K_I, K_F) \times 32$	A
"Aggregate data rate"	+	RS Coding overhead rate	=	"Total data rate"	$\Sigma(N_I, N_F) \times 32$	B
"Total data rate"	+	Trellis Coding overhead rate	=	Line rate	$\Sigma\, b_i \times 4$	U

6.3 ADSL system overheads and total bit rates

The total bit rate transmitted by the ADSL system when operating in an optional reduced-overhead framing mode shall include capacity for:

- the data rate transmitted in the ADSL bearer channels;
- ADSL system overhead, which includes:
  - an ADSL embedded operations channel, EOC;
  - an ADSL overhead control channel, AOC;
  - CRC check bytes;
  - fixed indicator bits for OAM;
  - FEC redundancy bytes.

When operating in the full-overhead mode, the total bit rate shall also include capacity for the synchronization control bytes and capacity for bearer channel synchronization control.

The above data streams shall be organized into ADSL frames and superframes as defined in 7.4 and 8.4 for the downstream and upstream data, respectively.

The internal overhead channels and their rates are shown in Table 6-4.

Table 6-4/G.992.1 – Internal overhead channel functions and rates

	Downstream rate (kbit/s) minimum/maximum		Upstream rate (kbit/s) minimum/maximum	
	Number of ASx bearer channels > 1	**Number of ASx bearer channels = 1**	**Number of LSx bearer channels > 1**	**Number of LSx bearer channels = 1**
Synchronization control, CRC and AOC; interleaved buffer	32/32	32/32	32/32	32/32
Synchronization control, CRC, EOC and indicator bits; fast buffer	32/32	32/32	32/32	32/32
Total for reduced overhead framing	32/64 (Note 2)	32/64 (Note 2)	32/64 (Note 2)	32/64 (Note 2)
Synchronization capacity (shared among all bearer channels)	64/128 (Note 3)	64/96 (Note 3)	32/64 (Note 3)	32/32 (Note 3)
Total (Note 1)	128/192	128/160	96/128	96/96

NOTE 1 – The overhead required for FEC is not shown in this table.

NOTE 2 – With the reduced overhead framing modes, a 32 kbit/s ADSL system overhead is present in each buffer type. However, when all ASx and LSx are allocated to one buffer type, synchronization control, CRC, EOC, AOC and indicator bits may be carried in a single 32 kbit/s ADSL system overhead present in the buffer type used. With full overhead framing, a 32 kbit/s ADSL system overhead is always present in each buffer type.

NOTE 3 – The shared synchronization capacity includes 32 kbit/s shared among LSx within the interleave buffer, 32 kbit/s shared among LSx within the fast buffer, 32 kbit/s shared among ASx within the interleave buffer, and 32 kbit/s shared among ASx within the fast buffer. The maximum rate occurs when at least one ASx is allocated to each type of buffer; the minimum rate occurs when all ASx and LSx are allocated to one buffer type.

7 ATU-C functional characteristics

An ATU-C may support STM transmission or ATM transmission or both. If STM is supported it shall be as defined in 7.1. If ATM is supported it shall be as defined in 7.2.

Framing modes that shall be supported depend upon the ATU-C being configured for either STM or ATM transport, and are defined in 7.1.5 and 7.2.4 respectively. If framing mode k is supported, then modes k-1, …, 0 shall also be supported.

During initialization, the ATU-C and ATU-R shall indicate a framing mode number 0, 1, 2 or 3 which they intend to use. The lowest indicated framing mode shall be used (see 10.6.4 and 10.7.6).

Using framing mode 0 ensures than an STM based ATU-x with an external ATM TC will interoperate with an ATM based ATU-x. Additional modes of interoperation are possible depending upon optional features provided in either ATU-x.

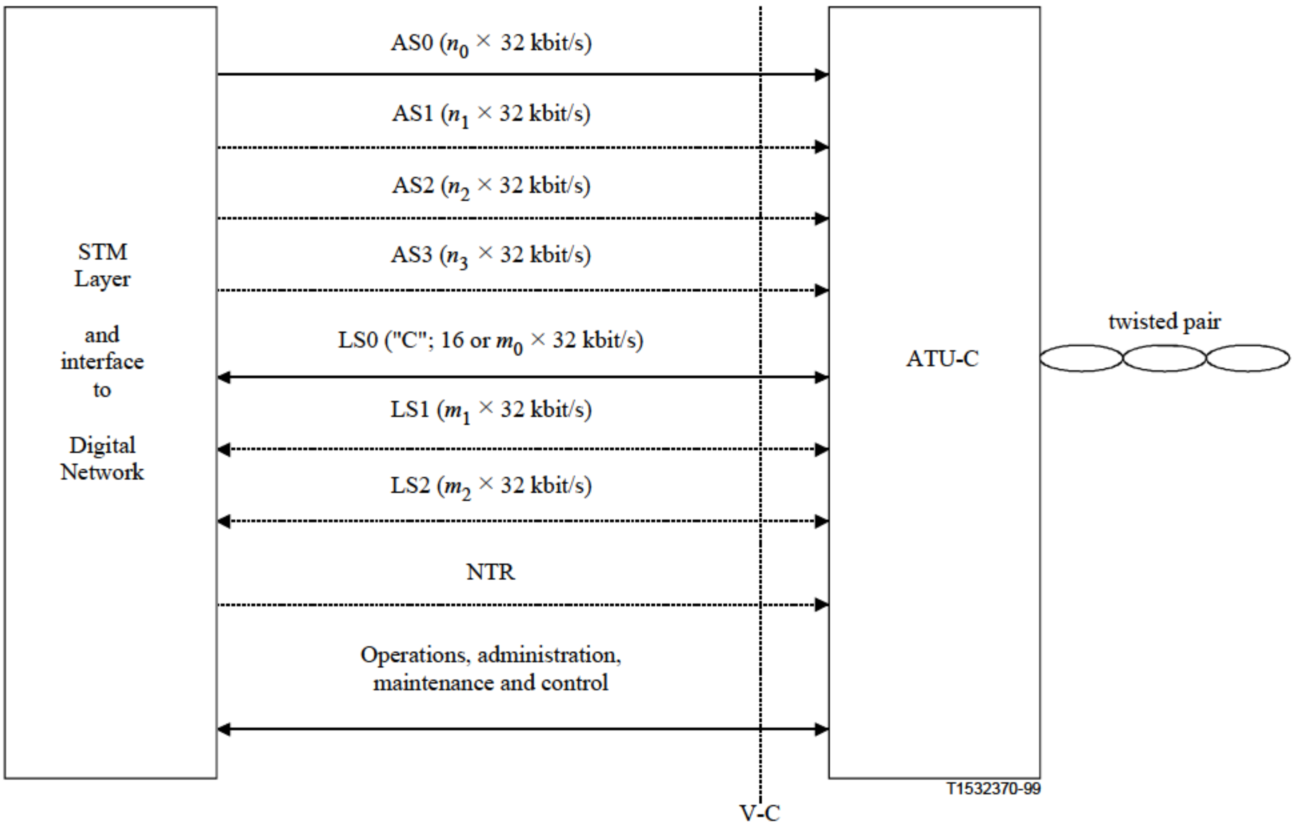
An ATU-C may provide a Network Timing Reference (NTR). This operation shall be independent of any clocking that is internal to the ADSL system. If provided, the NTR shall be inserted in the U-C framing structure as described in 7.3.2.

7.1 STM Transmission Protocol Specific functionalities

7.1.1 ATU-C input and output V interfaces for STM transport

The functional data interfaces at the ATU-C for STM transport are shown in Figure 7-1. Input interfaces for the high-speed downstream simplex bearer channels are designated AS0 through AS3; input/output interfaces for the duplex bearer channels are designated LS0 through LS2. There shall also be a duplex interface for operations, administration, maintenance (OAM) and control of the ADSL system.

The data rates of the input and output data interfaces at the ATU-C are specified in 6.1. The data rate at a given interface shall match the rate of the bearer channel configured to that interface.



NOTE – Optional bearer channels (both duplex and simplex) and features are shown with dotted lines.

Figure 7-1/G.992.1 – ATU-C functional interfaces for STM transport at the V-C reference point

7.1.2 Downstream simplex channels – bit rates

Four data input interfaces are defined at the ATU-C for the high-speed downstream simplex channels: AS0, AS1, AS2 and AS3 (ASx in general). The required data rate configurations are specified in 6.1.

7.1.3 Downstream/upstream duplex channels – bit rates

Three input and output data interfaces are defined at the ATU-C for the duplex channels supported by the ADSL system; LS0, LS1, and LS2 (LSx in general). The required data rate configurations are specified in 6.1.

LS0 is also known as the "C" or control channel. It carries the signalling associated with the ASx bearer channels and it may also carry some or all of the signalling associated with the other duplex bearer channels.

7.1.4 Payload transfer delay

The one-way transfer delay for payload bits in all bearers (simplex and duplex) from the V reference point at central office end (V-C) to the T reference point at remote end (T-R) for channels assigned to the fast buffer shall be no more than 2 ms, and for channels assigned to the interleave buffer it shall be no more than $(4 + (S - 1)/4 + SxD/4)$ ms, where S and D are defined in 7.6. The same requirement applies in the opposite direction, from the T-R reference point to the V-C reference point.

7.1.5 Framing Structure for STM transport

An ATU-C configured for STM transport shall support the full overhead framing structure 0 as specified in 7.4. The support of full overhead framing structure 1 and the reduced overhead framing structures 2 and 3 is optional.

Preservation of V-C interface byte boundaries (if present) at the U-C interface may be supported for any of the U-C interface framing structures.

An ATU-C configured for STM transport may support insertion of a Network Timing Reference (NTR). If inserted, the NTR shall be inserted in the U-C framing structure as described in 7.3.2.

7.2 ATM Transport Protocol Specific functionalities

7.2.1 ATU-C input and output V interface for ATM transport

The functional data interfaces at the ATU-C for ATM are shown in Figure 7-2. The ATM channel ATM0 shall always be provided, the channel ATM1 is optional and may be provided for support of dual latency mode. Each channel operates as an interface to a physical layer pipe. When operating in dual latency mode, no fixed allocation between the ATM channels 0 and 1, on one hand, and transport of "fast" and "interleaved" data, on the other hand, is assumed. This relationship is configured inside the ATU-C.

Flow control functionality shall be available on the V reference point to allow the ATU-C (i.e. the physical layer) to control the cell flow to and from the ATM layer. This functionality is represented by Tx_Cell_Handshake and Rx_Cell_Handshake. A cell may be transferred from ATM to PHY layer only after the ATU-C has activated the Tx_Cell_Handshake. Similarly a cell may be transferred from the PHY layer to the ATM layer only after the Rx_Cell_Handshake. This functionality is important to avoid cell overflow or underflow in the ATU-C and ATM layers.

There shall also be a duplex interface for operations, administration, maintenance (OAM) and control of the ADSL system.

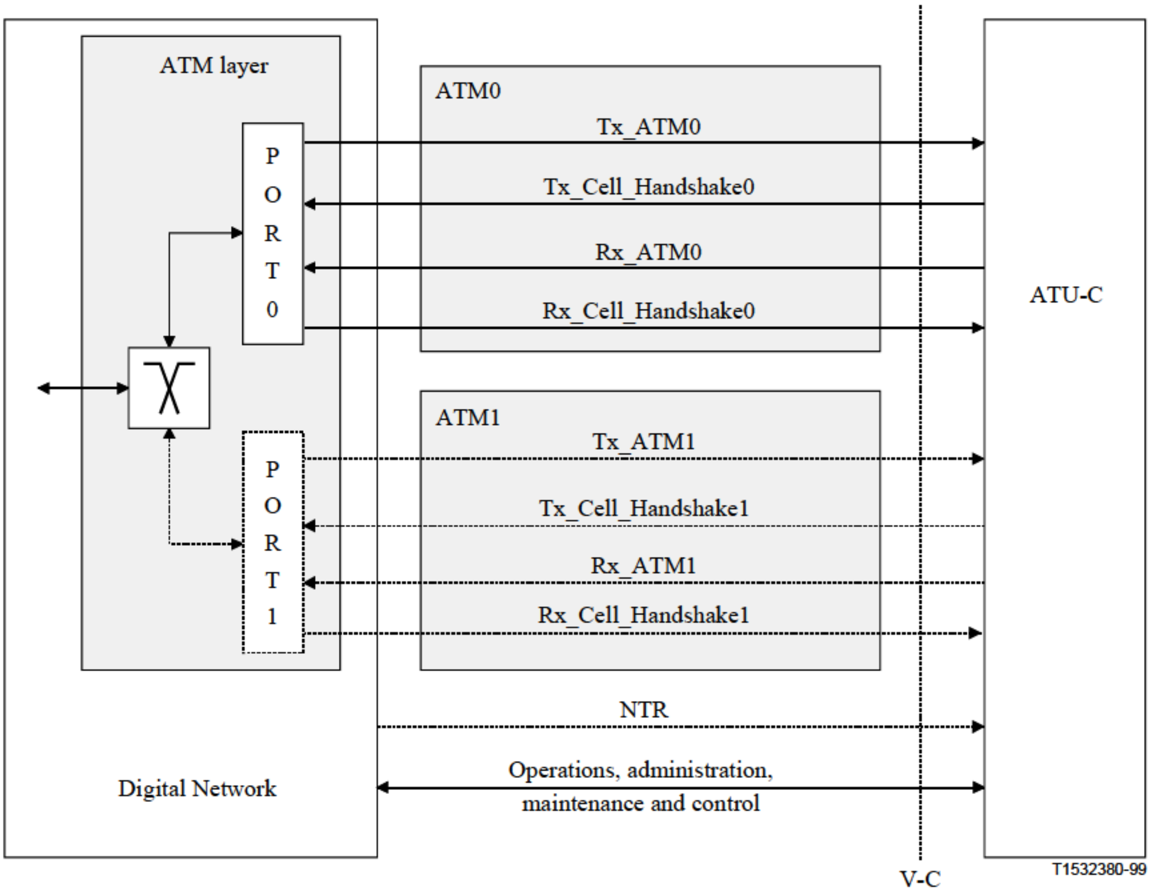


Figure 7-2/G.992.1 – ATU-C functional interfaces to the ATM layer at the V-C reference point

7.2.2 Payload transfer delay

The one-way transfer delay (excluding cell specific functionalities) for payload bits in all bearers (simplex and duplex) from the V reference point at central office end (V-C) to the T reference point at remote end (T-R) for channels assigned to the fast buffer shall be no more than 2 ms, and for channels assigned to the interleave buffer it shall be no more than $(4 + (S - 1)/4 + SxD/4)$ ms, where S and D are defined in 7.6. The same requirement applies in the opposite direction, from the T-R reference point to the V-C reference point.

NOTE – The additional delay introduced by the cell specific functionalities is implementation specific.

7.2.3 ATM Cell specific functionalities

7.2.3.1 Idle Cell Insertion

Idle cells shall be inserted in the transmit direction for cell rate decoupling. Idle cells are identified by the standardized pattern for the cell header given in Recommendation I.432.1.

NOTE – This Recommendation is written on the assumption that idle cells will be discarded by an ATU-R receiver.

7.2.3.2 Header Error Control (HEC) Generation

The HEC byte shall be generated in the transmit direction as described in Recommendation I.432.1, including the recommended modulo 2 addition (XOR) of the pattern 01010101_2 to the HEC bits.

The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with Recommendation I.432.1.

7.2.3.3 Cell payload scrambling

Scrambling of the cell payload field shall be used in the transmit direction to improve the security and robustness of the HEC cell delineation mechanism. In addition, it randomizes the data in the information field, for possible improvement of the transmission performance. The self synchronizing scrambler polynomial $X^{43} + 1$ and procedures defined in Recommendation I.432.1 shall be implemented.

NOTE – This Recommendation is written on the assumption that the cell payload will be descrambled by an ATU-R receiver.

7.2.3.4 Bit timing and ordering

When interfacing ATM data bytes to the AS0 or AS1 bearer channel, the most significant bit (MSB) shall be sent first. The AS0 or AS1 bearer channel data rates shall be integer multiples 32 kbit/s, with bit timing synchronous with the ADSL downstream modem timing base (see 7.4.2.1 and 7.4.2.2).

7.2.3.5 Cell Delineation

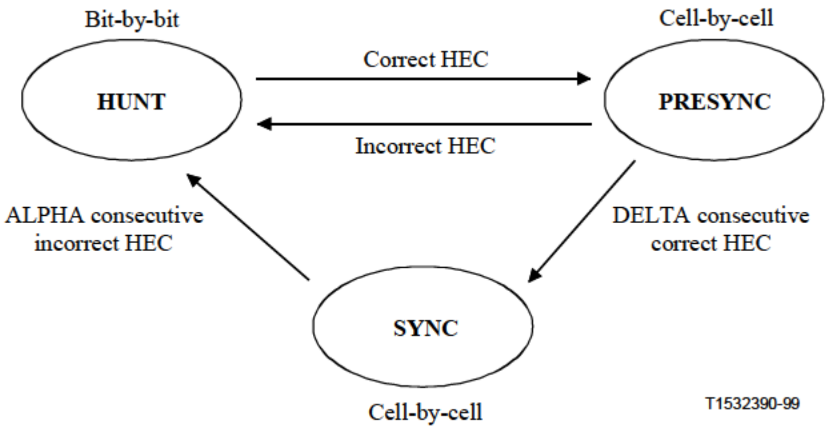
The cell delineation function permits the identification of cell boundaries in the payload. It uses the HEC field in the cell header.

Cell delineation shall be performed using a coding law checking the HEC field in the cell header according to the algorithm described in Recommendation I.432.1. The ATM cell delineation state machine is shown in Figure 7-3. The details of the state diagram are described below:

1) In the HUNT state, the delineation process is performed by checking bit-by-bit for the correct HEC. Once such an agreement is found, it is assumed that one header has been found, and the method enters the PRESYNC state. When byte boundaries are available within the receiving Physical Layer prior to cell delineation as with the framing modes 1, 2 and 3 (see 7.4), the cell delineation process may be performed byte-by-byte.

2) In the PRESYNC state, the delineation process is performed by checking cell-by-cell for the correct HEC. The process repeats until the correct HEC has been confirmed *DELTA* (see Note) times consecutively. If an incorrect HEC is found, the process returns to the HUNT state.

3) In the SYNC state, the cell delineation will be assumed to be lost if an incorrect HEC is obtained *ALPHA* times consecutively.



NOTE – With reference to Recommendation I.432.1, no recommendation is made for the values of ALPHA and DELTA as the choice of these values is not considered to effect interoperability. However, it should be noted that the use of the values suggested in Recommendation I.432 (ALPHA = 7, DELTA = 6) may be inappropriate due to the particular transmission characteristics of ADSL.

Figure 7-3/G.992.1 – ATM cell delineation state machine

7.2.3.6 Header Error Control Verification

The HEC covers the entire cell header. The code used for this function is capable of either:

- single bit error correction; or
- multiple bit error detection.

Error detection shall be implemented as defined in Recommendation I.432.1 with the exception that any HEC error shall be considered as a multiple bit error, and therefore, HEC error correction shall not be performed.

7.2.4 Framing Structure for ATM transport

An ATU-C configured for ATM transport shall support the full overhead framing structures 0 and 1 as specified in 7.4. The support of reduced overhead framing structures 2 and 3 is optional.

The ATU-C transmitter shall preserve V-C interface byte boundaries (explicitly present or implied by ATM cell boundaries) at the U-C interface, independent of the U-C interface framing structure.

To ensure framing structure 0 interoperability between an ATM ATU-C and an ATM cell TC plus an STM ATU-R (i.e. ATM over STM), the following shall apply:

- an STM ATU-R transporting ATM cells and not preserving T-R byte boundaries at the U-R interface shall indicate during initialization that frame structure 0 is the highest frame structure supported;
- an STM ATU-R transporting ATM cells and preserving T-R byte boundaries at the U-R interface shall indicate during initialization that frame structure 0, 1, 2 or 3 is the highest frame structure supported, as applicable to the implementation;
- an ATM ATU-C receiver operating in framing structure 0 cannot assume that the ATU-R transmitter will preserve T-R interface byte boundaries at the U-R interface and shall therefore perform the cell delineation bit-by-bit (see 7.2.3.5).

An ATU-C configured for ATM transport may support insertion of a Network Timing Reference (NTR). The network operator may choose not to insert the NTR. If inserted, the NTR shall be inserted in the U-C framing structure as described in 7.3.2.

7.3 Network timing reference (NTR)

7.3.1 Need for NTR

Some services require that a reference clock be available in the higher layers of the protocol stack (i.e. above the physical layer); this is used to guarantee end-to-end synchronization of transmit and receive sides. Examples are Voice and Telephony Over ATM (VTOA) and Desktop Video Conferencing (DVC).

To support the distribution of a timing reference over the network, the ADSL system may transport an 8 kHz timing marker as NTR. This 8 kHz timing marker may be used for voice/video playback at the decoder (D/A converter) in DVC and VTOA applications. The 8 kHz timing marker is input to the ATU-C as part of the interface at the V-C reference point.

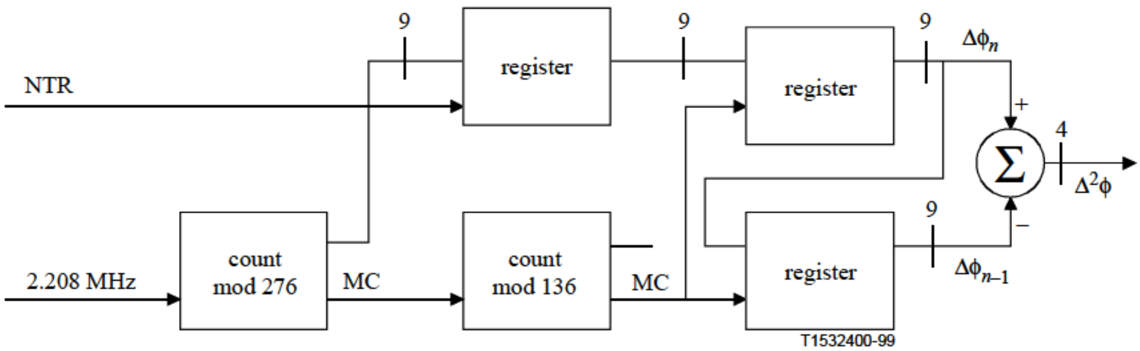
7.3.2 Transport of the NTR

The intention of the NTR transport mechanism is that the ATU-C should provide timing information at the U-C reference point to enable the ATU-R to deliver to the T-R reference point timing information that has a timing accuracy corresponding to the accuracy of the clock provided to the V-C reference point. If provided, the NTR shall be inserted in the U-C framing structure as follows:

- The ATU-C may generate an 8 kHz local timing reference (LTR) by dividing its sampling clock by the appropriate integer (276 if 2.208 MHz is used).
- It shall transmit the change in phase offset between the input NTR and LTR (measured in cycles of the 2.208 MHz clock, that is, units of approximately 452 ns) from the previous superframe to the present one; this shall be encoded into four bits ntr3-ntr0 (with ntr3 the MSB), representing a signed integer in the –8 to +7 range in 2's-complement notation. The bits ntr3-ntr0 shall be carried in the indicator bits 23 (ntr3) to 20 (ntr0); see Table 7-2.
- A positive value of the change of phase offset, $\Delta^2\phi$ shall indicate that the LTR is higher in frequency than the NTR.
- Alternatively, the ATU-C may choose to lock its downstream sampling clock (2.208 MHz) to 276 times the NTR frequency; in that case it shall encode $\Delta^2\phi$ to zero.

The NTR has a maximum frequency variation of ±32 ppm. The LTR, as specified in 7.11.1, has a maximum frequency variation of ±50 ppm. The maximum mismatch is therefore ±82 ppm. This would result in an average change of phase offset of approximately ±3.5 clock cycles over one 17 ms superframe, which can be mapped into 4 overhead bits.

One method that the ATU-C may use to measure this change of phase offset is shown in Figure 7-4.



(MC is maxcount indication before foldover to 0)

Figure 7-4/G.992.1 – Example implementation of the $\Delta^2\phi$ measurement

7.4 Framing

This subclause specifies framing of the downstream signal (ATU-C transmitter). The upstream framing (ATU-R transmitter) is specified in 8.4.

Two types of framing are defined: full overhead and reduced overhead. Furthermore, two versions of full overhead and two versions of reduced overhead are defined. The four resulting framing modes are defined in Table 7-1 and shall be referred to as framing modes 0, 1, 2 and 3.

Table 7-1/G.992.1 – Definition of framing modes

Framing structure	Description
0	Full overhead framing with asynchronous bit-to-modem timing (see 7.4.1) (i.e. enabled synchronization control mechanism, see 7.4.2)
1	Full overhead framing with synchronous bit-to-modem timing (see 7.4.1) (i.e. disabled synchronization control mechanism, see 7.4.2)
2	Reduced overhead framing with separate fast and sync byte in fast and interleaved latency buffer respectively (i.e. 64 kbit/s framing overhead) (see 7.4.3.1)
3	Reduced overhead framing with merged fast and sync byte, using either the fast or the interleaved latency buffer (i.e. 32 kbit/s framing overhead) (see 7.4.3.2)

Requirements for framing modes to be supported depend upon the ATU-C being configured for either STM or ATM transport, and are defined in 7.1.5 and 7.2.4 respectively.

The ATU-C shall indicate during initialization the highest framing structure number it supports. If the ATU-C indicates it supports framing structure k, it shall also support all framing structures $k - 1$ to 0. If the ATU-R indicates a lower framing structure number during initialization, the ATU-C shall fall back to the framing structure number indicated by the ATU-R.

As specified in clause 5, outside the ASx/LSx serial interfaces data bytes are transmitted MSB first in accordance with Recommendations G.703, G.709, I.361, and I.432.1. All serial processing in the ADSL frame (e.g. CRC, scrambling, etc.) shall, however, be performed LSB first, with the outside world MSB considered by the ADSL as LSB. As a result, the first incoming bit (outside world MSB) will be the first processed bit inside the ADSL (ADSL LSB).

7.4.1 Data symbols

Figures 5-1 and 5-2 show functional block diagrams of the ATU-C transmitter with reference points for data framing. Up to four downstream simplex data channels and up to three duplex data channels shall be synchronized to the 4 kHz ADSL DMT frame rate, and multiplexed into two separate data buffers (fast and interleaved). A cyclic redundancy check (CRC), scrambling, and forward error correction (FEC) coding shall be applied to the contents of each buffer separately, and the data from the interleaved buffer shall then be passed through an interleaving function. The two data streams shall then be tone ordered as defined in 7.7, and combined into a data symbol that is input to the constellation encoder. After constellation encoding, the data shall be modulated to produce an analogue signal for transmission across the customer loop.

A bit-level framing pattern shall not be inserted into the data symbols of the frame or superframe structure. DMT frame (i.e. symbol) boundaries are delineated by the cyclic prefix inserted by the modulator (see 7.12). Superframe boundaries are determined by the synchronization symbol, which shall also be inserted by the modulator, and which carries no user data (see 7.11.3).

Because of the addition of FEC redundancy bytes and data interleaving, the data frames (i.e. bit-level data prior to constellation encoding) have different structural appearance at the three reference points through the transmitter. As shown in Figures 5-1 and 5-2, the reference points for which data framing will be described in the following subclauses are:

- A (Mux data frame): the multiplexed, synchronized data after the CRC has been inserted (synchronization is described in 7.4.2, CRC is specified in 7.4.1.5. Mux data frames shall be generated at a nominal 4 kbaud (i.e. every 250 μs).
- B (FEC output data frame): the data frame generated at the output of the FEC encoder at the DMT symbol rate, where an FEC block may span more than one DMT symbol period.
- C (constellation encoder input data frame): the data frame presented to the constellation coder.

7.4.1.1 Superframe structure

ADSL uses the superframe structure shown in Figure 7-5. Each superframe is composed of 68 data frames, numbered from 0 to 67, which are encoded and modulated into DMT symbols, followed by a synchronization symbol, which carries no user or overhead bit-level data and is inserted by the modulator (see 7.11.3) to establish superframe boundaries. From the bit-level and user data perspective, the DMT symbol rate is 4000 baud (period = 250 μs), but in order to allow for the insertion of the synchronization symbol the transmitted DMT symbol rate is 69/68 × 4000 baud.

Each data frame within the superframe contains data from the fast buffer and the interleaved buffer. The size of each buffer depends on the assignment of bearer channels made during initialization (see 7.4.1.2 and 10.6.2).

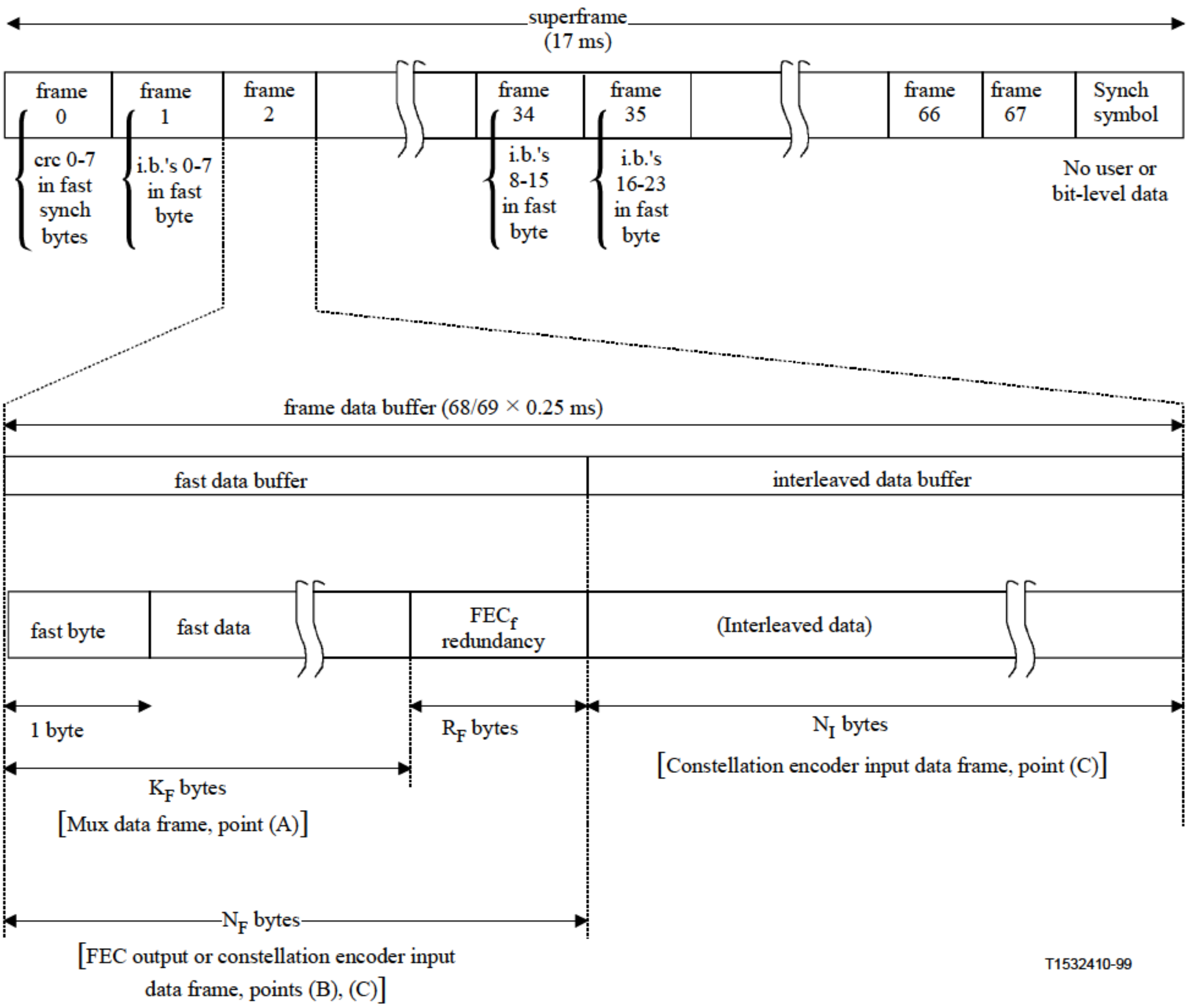


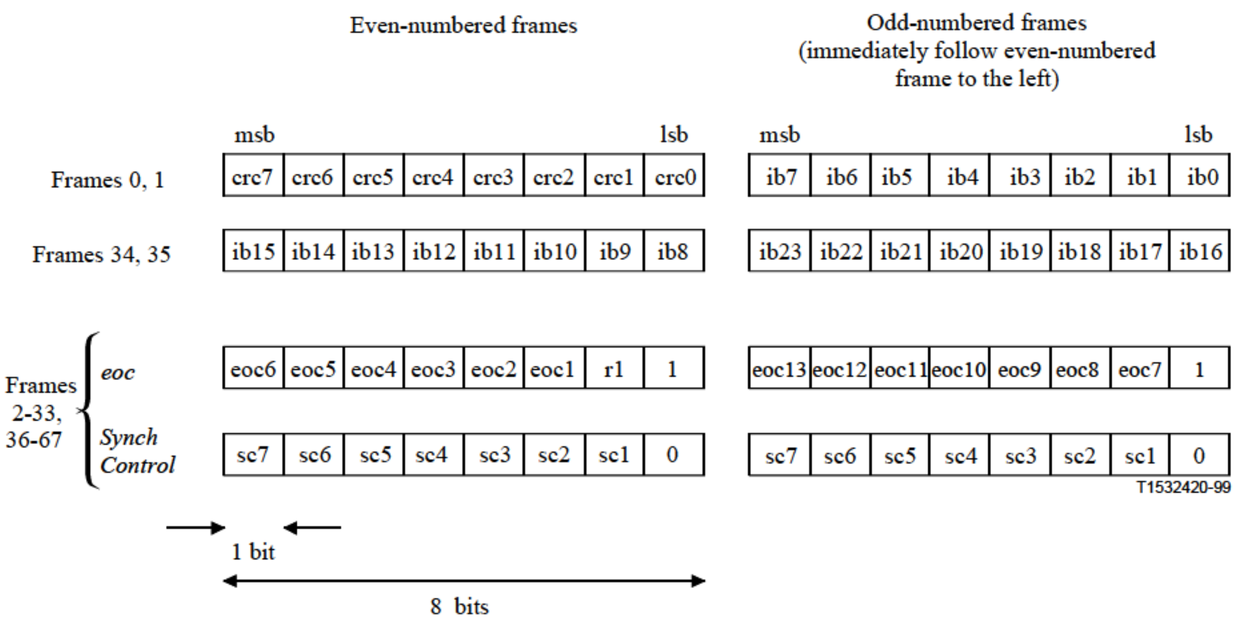
Figure 7-5/G.992.1 – ADSL superframe structure – ATU-C transmitter

During each ADSL superframe, eight bits shall be reserved for the CRC on the fast data buffer (crc0-crc7), and 24 indicator bits (ib0-ib23) shall be assigned for OAM functions. As shown in Figure 7-6, the synchronization byte of the fast data buffer ("fast byte") carries the CRC check bits in frame 0 and the indicator bits in frames 1, 34 and 35. The fast byte in other frames is assigned in even-/odd-frame pairs to either the EOC or to synchronization control of the bearer channels assigned to the fast buffer.

Bit 0 of the fast byte in an even-numbered frame (other than frames 0 and 34) and bit 0 of the fast byte of the odd-numbered frame immediately following shall be set to "0" to indicate these frames carry a synchronization control information.

When they are not required for synchronization control, CRC, or indicator bits, the fast bytes of two successive ADSL frames, beginning with an even-numbered frame, may contain indications of "no synchronization action" (see 7.4.2), or alternatively, they may be used to transmit one EOC message, consisting of 13 bits. The indicator bits are defined in Table 7-2.

Bit 0 of the fast byte in an even-numbered frame (other than frames 0 and 34) and bit 0 of the fast byte of the odd-numbered frame immediately following shall be set to "1" to indicate these frames carry a 13-bit EOC message plus one additional bit, r1 (see clause 9). The r1 bit is reserved for future use and shall be set to "1".



In all frames bit 7 = MSB and bit 0 = LSB.

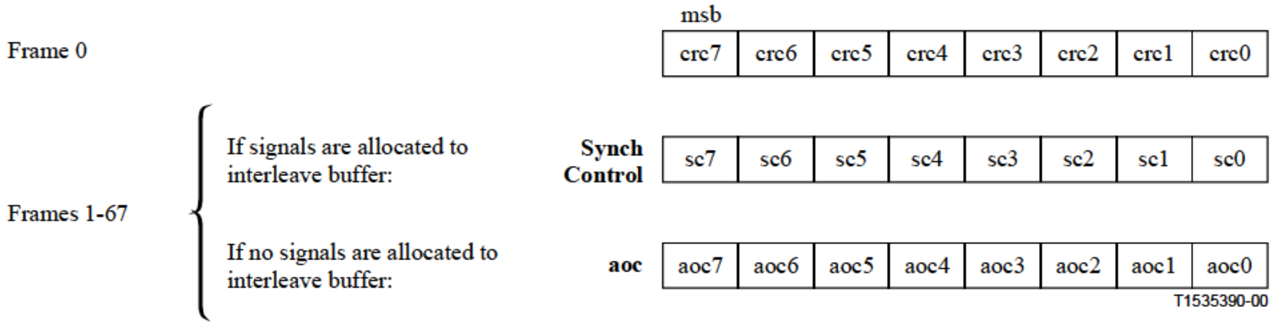
Figure 7-6/G.992.1 – Fast synchronization byte ("fast byte") format – ATU-C transmitter

Table 7-2/G.992.1 – Definition of indicator bits, ATU-C transmitter (fast data buffer, downstream direction)

Indicator bit (Note 1)	Definition (Note 2)
Ib0-ib7	Reserved for future use
Ib8	FEBE-I
Ib9	FECC-I
Ib10	FEBE-F
Ib11	FECC-F
Ib12	LOS
Ib13	RDI
Ib14	NCD-I (used for ATM only, shall be set to "1" for STM)
Ib15	NCD-F (used for ATM only, shall be set to "1" for STM)
Ib16	HEC-I (used for ATM only, shall be set to "1" for STM)
Ib17	HEC-F (used for ATM only, shall be set to "1" for STM)
Ib18-19	Reserved for future use
Ib20-23	NTR0-3 (if NTR is not transported, ib20-23 shall be set to "1" – they are active low)
NOTE 1 – See 9.3.1 for the definition of the bits and their use. NOTE 2 – Because all indicator bits are defined as active low, reserved bits shall be set to "1".	

Eight bits per ADSL superframe shall be used for the CRC on the interleaved data buffer (crc0-crc7). As shown in Figures 7-7 and 7-9, the synchronization byte of the interleaved data buffer ("sync byte") carries the CRC check bits for the previous superframe in frame 0. In all other frames (1 through 67), the sync byte shall be used for synchronization control of the bearer channels assigned to the interleaved data buffer or used to carry an ADSL overhead control (AOC) channel. In the full overhead mode (see 7.4.1.2), when any bearer channel appears in the interleave buffer, then

the AOC data shall be carried in the LEX byte, and the sync byte shall designate when the LEX byte contains AOC data and when it contains data bytes from the bearer channel. When no bearer channels are allocated to the interleave data buffer (i.e. all $B_i(ASx) = B_i(LSx) = 0$), then the sync byte shall carry the AOC data directly (AEX and LEX bytes, described in 7.4.1.2, do not exist in the interleaved buffer in this case). The format of the sync byte is described in 7.4.2.2.



NOTE – The names "fast byte" and "sync byte" are abbreviations for, and are used interchangeably with, "fast synchronization byte" and "interleaved synchronization byte", respectively.

Figure 7-7/G.992.1 – Interleaved synchronization byte ("sync byte") format – ATU-C transmitter

7.4.1.2 Frame structure (with full overhead)

Each data frame shall be encoded into a DMT symbol, as described in 7.7 through 7.9. As is shown in Figure 7-5, each frame is composed of a fast data buffer and an interleaved data buffer, and the frame structure has a different appearance at each of the reference points (A, B and C). The bytes of the fast data buffer shall be clocked into the constellation encoder first, followed by the bytes of the interleaved data buffer. Bytes are clocked least significant bit first.

Each bearer channel shall be assigned to either the fast or the interleaved buffer during initialization (see 10.6.2), and a pair of bytes, $[B_F, B_I]$, transmitted for each bearer channel, where B_F and B_I designate the number of bytes allocated to the fast and interleaved buffers, respectively.

The seven $[B_F, B_I]$ pairs to specify the downstream bearer channel rates are:

- B_F(ASx), B_I(ASx) for X = 0, 1, 2 and 3, for the downstream simplex channels;
- B_F(LSx), B_I(LSx) for X = 0, 1 and 2, for the (downstream transport of the) duplex channels.

The rules for allocation are:

- for any bearer channel, X, except the 16 kbit/s C-channel option, either B_F(X) = the number of bytes per frame of the fast buffer and B_I(X) = 0, or B_F(X) = 0 and B_I(X) = the number of bytes per frame of the interleaved buffer;
- for the 16 kbit/s C-channel option, B_F(LS0) = 255 (11111111_2) and B_I(LS0) = 0, or B_F(LS0) = 0 and B_I(LS0) = 255.

7.4.1.2.1 Fast data buffer (with full overhead)

The frame structure of the fast data buffer shall be as shown in Figure 7-8 for reference points A and B, which are defined in Figures 5-1 and 5-2.

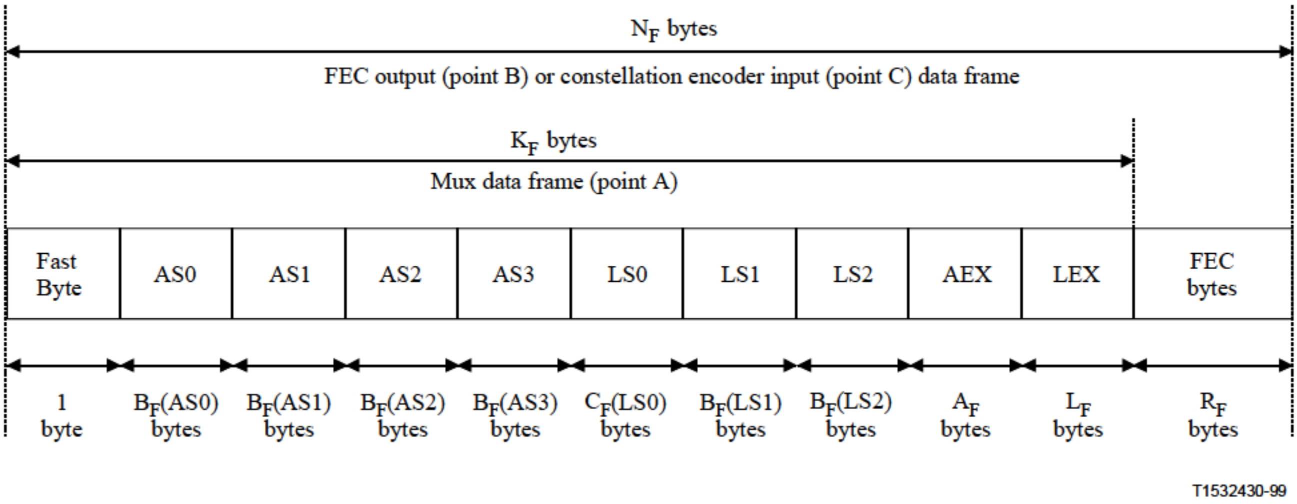


Figure 7-8/G.992.1 – Fast data buffer – ATU-C transmitter

The following shall hold for the parameters shown in Figure 7-8:

$$C_F(LS0) = 0 \quad \text{if } B_F(LS0) = 255(11111111_2) \qquad (7\text{-}1)$$
$$= B_F(LS0) \quad \text{otherwise}$$

$$N_F = K_F + R_F \qquad (7\text{-}2)$$

where R_F = number of FEC redundancy bytes, and

$$K_F = 1 + \sum_{i=0}^{3} B_F(ASi) + A_F + C_F(LS0) + \sum_{j=1}^{2} B_F(LSj) + L_F \qquad (7\text{-}3)$$

where:

$$A_F = 0 \quad \text{if } \sum_{i=0}^{3} B_F(ASi) = 0 \qquad (7\text{-}4)$$
$$= 1 \quad \text{otherwise}$$

and:

$$L_F = 0 \quad \text{if } B_f(ASi) = 0 \text{ for } i = 0-3 \text{ and } B_f(LSj) = 0 \text{ for } j = 0-2 \qquad (7\text{-}5)$$
$$= 1 \quad \text{otherwise (including } B_F(LS0) = 255)$$

At reference point A (Mux data frame) in Figures 5-1 and 5-2, the fast buffer shall always contain at least the fast byte. This is followed by B_F(AS0) bytes of channel AS0, then B_F(AS1) bytes of channel AS1, B_F(AS2) bytes of channel AS2 and B_F(AS3) bytes of channel AS3. Next come the bytes for any duplex (LSx) channels allocated to the fast buffer. If any B_F(ASx) is non-zero, then both an AEX and an LEX byte follow the bytes of the last LSx channel, and if any B_F(LSx) is non-zero, the LEX byte shall be included.

When B_F(LS0) = 255, no bytes are included for the LS0 channel. Instead, the 16 kbit/s C-channel shall be transported in every other LEX byte on average, using the sync byte to denote when to add the LEX byte to the LS0 bearer channel.

R_F FEC redundancy bytes shall be added to the mux data frame (reference point A) to produce the FEC output data frame (reference point B), where R_F is given in the RATES1 options used during

initialization.

Because the data from the fast buffer is not interleaved, the constellation encoder input data frame (reference point C) is identical to the FEC output data frame (reference point B).

7.4.1.2.2 Interleaved data buffer (with full overhead)

The frame structure of the interleaved data buffer is shown in Figure 7-9 for reference points A and B, which are defined in Figures 5-1 and 5-2.

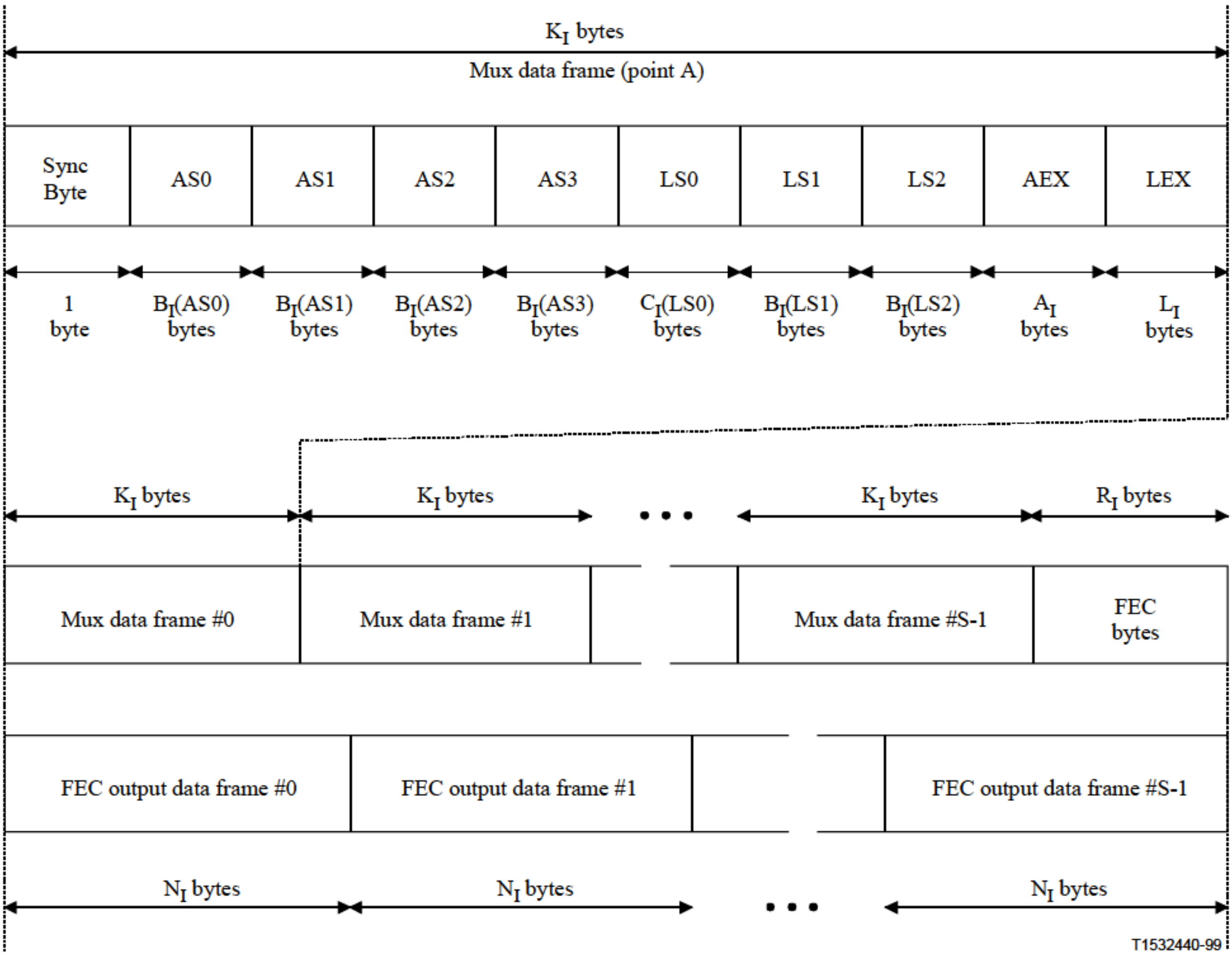


Figure 7-9/G.992.1 – Interleaved data buffer, ATU-C transmitter

The following shall hold for the parameters shown in Figure 7-9:

$$C_I(LS0) = 0 \quad \text{if } B_I(LS0) = 255(11111111_2) \tag{7-6}$$

$$= B_I(\mathrm{LS0}) \quad \text{otherwise}$$

$$N_I = (S \times K_I + R_I)/S \tag{7-7}$$

where R_I = number of FEC redundancy bytes and S = number of DMT symbols per FEC codeword.

$$K_I = 1 + \sum_{i=0}^{3} B_I(ASi) + A_I + C_I(LS0) + \sum_{j=1}^{2} B_I(LSj) + L_I \tag{7-8}$$

where:

$$A_I = 0 \qquad \text{if } \sum_{i=0}^{3} BI(ASi) = 0 \qquad (7\text{-}9)$$
$$= 1 \qquad \text{otherwise}$$

and:

$$L_I = 0 \quad \text{if } B_I(ASi) = 0 \text{ for } i = 0-3 \text{ and } B_I(LSj) = 0 \text{ for } j = 0-2 \qquad (7\text{-}10)$$
$$= 1 \quad \text{otherwise (including } B_I(LS0) = 255)$$

At reference point A, the Mux data frame, the interleaved data buffer shall always contain at least the sync byte. The rest of the buffer shall be built in the same manner as the fast buffer, substituting B_I in place of B_F. The length of each mux data frame is K_I bytes, as defined in Figure 7-9.

The FEC coder shall take in S mux data frames and append R_I FEC redundancy bytes to produce the FEC codeword of length $N_{FEC} = S \times K_I + R_I$ bytes. The FEC output data frames shall contain $N_I = N_{FEC}/S$ bytes, where N_I is an integer. When $S > 1$, then for the S frames in an FEC codeword, the FEC output Data Frame (reference point B) shall partially overlap two mux data frames for all except the last frame, which shall contain the R_I FEC redundancy bytes.

The FEC output data frames are interleaved to a specified interleave depth. The interleaving process (see 7.6.3) delays each byte of a given FEC output data frame a different amount, so that the constellation encoder input data frames will contain bytes from many different FEC data frames. At reference point A in the transmitter, mux data frame 0 of the interleaved data buffer is aligned with the ADSL superframe and mux data frame 0 of the fast data buffer (this is not true at reference point C). At the receiver, the interleaved data buffer will be delayed by ($S \times$ interleave depth $\times$ 250) µs with respect to the fast data buffer, and data frame 0 (containing the CRC bits for the interleaved data buffer) will appear a fixed number of frames after the beginning of the receiver superframe.

7.4.1.3 Hyperframe Structure (Annex C only)

For Annex C, see C.4.3.2.

7.4.1.4 Subframe Structure (Annex C only)

For Annex C, see C.4.3.3.

7.4.1.5 Cyclic redundancy check (CRC)

Two cyclic redundancy checks (CRCs) – one for the fast data buffer and one for the interleaved data buffer – shall be generated for each superframe and transmitted in the first frame of the following superframe. Eight bits per buffer type (fast or interleaved) per superframe are allocated to the CRC check bits (7.4.1.1). These bits are computed from the k message bits using the equation:

$$\mathrm{crc(D)} = M(\mathrm{D})\,\mathrm{D}^8 \text{ modulo } G(\mathrm{D}) \qquad (7\text{-}11)$$

where:

$$M(\mathrm{D}) = m_0\mathrm{D}^{k-1} + m_1\mathrm{D}^{k-2} + \ldots + m_{k-2}\mathrm{D} + m_{k-1} \qquad (7\text{-}12)$$

is the message polynomial,

$$G(\mathrm{D}) = \mathrm{D}^8 + \mathrm{D}^4 + \mathrm{D}^3 + \mathrm{D}^2 + 1 \qquad (7\text{-}13)$$

is the generating polynomial,

$$\mathrm{crc(D)} = c_0\,\mathrm{D}^7 + c_1\mathrm{D}^6 + \ldots + c_6\,\mathrm{D} + c_7 \qquad (7\text{-}14)$$

is the check polynomial, and D is the delay operator. That is, CRC is the remainder when $M(D)\ D^8$ is divided by $G(D)$. The CRC check bits are transported in the synchronization bytes (fast and interleaved, 8 bits each) of frame 0 for each data buffer.

The bits (i.e. message polynomials) covered by the CRC include:

- fast data buffer:
  - frame 0: ASx bytes ($X = 0, 1, 2, 3$), LSx bytes ($X = 0, 1, 2$), followed by any AEX and LEX bytes;
  - all other frames: fast byte, followed by ASx bytes ($X = 0, 1, 2, 3$), LSx bytes ($X = 0, 1, 2$), and any AEX and LEX bytes.
- interleaved data buffer:
  - frame 0: ASx bytes ($X = 0, 1, 2, 3$), LSx bytes ($X = 0, 1, 2$), followed by any AEX and LEX bytes;
  - all other frames: sync byte, followed by ASx bytes ($X = 0, 1, 2, 3$), LSx bytes ($X = 0, 1, 2$), and any AEX and LEX bytes.

Each byte shall be clocked into the CRC least significant bit first.

The number of bits over which the CRC is computed varies with the allocation of bytes to the fast and interleaved data buffers (the numbers of bytes in ASx and LSx vary according to the $[B_F,B_I]$ pairs; AEX is present in a given buffer only if at least one ASx is allocated to that buffer; LEX is present in a given buffer only if at least one ASx or one LSx is allocated to that buffer).

Because of the flexibility in assignment of bearer channels to the fast and interleaved data buffers, CRC field lengths over an ADSL superframe will vary from approximately 67 bytes to approximately 14 875 bytes.

7.4.2 Synchronization

If the bit timing base of the input user data streams is not synchronous with the ADSL modem timing base, the input data streams shall be synchronized to the ADSL timing base using the synchronization control mechanism (consisting of synchronization control byte and the AEX and LEX bytes). Forward-error-correction coding shall always be applied to the synchronization control byte(s).

If the bit timing base of the input user data streams is synchronous with the ADSL modem timing base, then the synchronization control mechanism is not needed, and the synchronization control byte shall always indicate "no synchronization action" (see Tables 7-3 and 7-4).

7.4.2.1 Synchronization for the fast data buffer

Synchronization control for the fast data buffer may occur in frames 2 through 33, and 36 through 67 of an ADSL superframe as described in 7.4.1.1, where the fast byte may be used as the synchronization control byte. No synchronization action shall be taken for those frames for which the fast byte is used for CRC, fixed indicator bits, or EOC.

The format of the fast byte when used as synchronization control for the fast data buffer shall be as given in Table 7-3.

Table 7-3/G.992.1 – Fast byte format for synchronization

Bits	Designation	Codes
sc7, sc6	ASx bearer channel designator	"00_2": AS0 "01_2": AS1 "10_2": AS2 "11_2": AS3
sc5, sc4	Synchronization control for the designated ASx bearer channel	"00_2": no synchronization action "01_2": add AEX byte to designated ASx bearer channel "11_2": add AEX and LEX bytes to ASx bearer channel "10_2": delete last byte from designated ASx bearer channel
sc3, sc2	LSx bearer channel designator	"00_2": LS0 "01_2": LS1 "10_2": LS2 "11_2": no synchronization action
sc1	Synchronization control for the designated LSx bearer channel	"1_2": add LEX byte to designated LSx bearer channel "0_2": delete last byte from designated LSx bearer channel
sc0	Synchronization/EOC designator	"0_2": perform synchronization control as indicated in sc7-sc1 "1_2": this byte is part of an EOC frame

ADSL deployments may need to interwork with DS1 (1.544 Mbit/s) or DS1C (3.152 Mbit/s) rates. The synchronization control option that allows adding up to two bytes to an ASx bearer channel provides sufficient overhead capacity to transport combinations of DS1 or DS1C channels transparently (without interpreting or stripping and regenerating the framing embedded within the DS1 or DS1C). The synchronization control algorithm shall, however, guarantee that the fast byte in some minimum number of frames is available to carry EOC frames, so that a minimum EOC rate (4 kbit/s) may be maintained.

When the data rate of the C-channel is 16 kbit/s, the LS0 bearer channel is transported in the LEX byte, using the "add LEX byte to designated LSx channel", with LS0 as the designated channel, every other frame on average.

If the bit timing base of the input bearer channels (ASx, LSx) is synchronous with the ADSL modem timing base then ADSL systems need not perform synchronization control by adding or deleting AEX or LEX bytes to/from the designated ASx and LSx channels, and the synchronization control byte shall indicate "no synchronization action" (i.e. sc7-0 coded "$XX0011X0_2$", with X discretionary).

7.4.2.2 Synchronization for the interleaved data buffer

Synchronization control for the interleaved data buffer can occur in frames 1 through 67 of an ADSL superframe as described in 7.4.1.1, where the sync byte may be used as the synchronization control byte. No synchronization action shall be taken during frame 0, where the sync byte is used for CRC during frames when the LEX byte carries the AOC.

The format of the sync byte when used as synchronization control for the interleaved data buffer shall be as given in Table 7-4. In the case where no signals are allocated to the interleaved data buffer, the sync byte shall carry the AOC data directly, as shown in Figure 7-7 in 7.4.1.1.

Table 7-4/G.992.1 – Sync byte format for synchronization

Bits	Designation	Codes
sc7, sc6	ASx bearer channel designator	"00_2": AS0 "01_2": AS1 "10_2": AS2 "11_2": AS3
sc5, sc4	Synchronization control for the designated ASx bearer channel	"00_2": no synchronization action "01_2": add AEX byte to designated ASx bearer channel "11_2": add AEX and LEX bytes to ASx bearer channel "10_2": delete last byte from designated ASx bearer channel
sc3, sc2	LSx bearer channel designator	"00_2": LS0 "01_2": LS1 "10_2": LS2 "11_2": no synchronization action
sc1	Synchronization control for the designated LSx bearer channel	"1_2": add LEX byte to designated LSx bearer channel "0_2": delete last byte from designated LSx bearer channel
sc0	Synchronization/AOC designator	"0_2": perform synchronization control as indicated in sc7-sc1 "1_2": LEX byte carries ADSL overhead control channel data; synchronization control is allowed for "add AEX" or "delete" as indicated in sc7-sc1

ADSL deployments may need to interwork with DS1 (1.544 Mbit/s) or DS1C (3.152 Mbit/s) rates. The synchronization control option that allows adding up to two bytes to an ASx bearer channel provides sufficient overhead capacity to transport combinations of DS1 or DS1C channels transparently (without interpreting or stripping and regenerating the framing embedded within the DS1 or DS1C).

When the data rate of the C-channel is 16 kbit/s, the LS0 bearer channel is transported in the LEX byte, using the "add LEX byte to designated LSx channel", with LS0 as the designated channel, every other frame on average.

If the bit timing base of the input bearer channels (ASx, LSx) is synchronous with the ADSL modem timing base then ADSL systems need not perform synchronization control by adding or deleting AEX or LEX bytes to/from the designated ASx and LSx channels, and the synchronization control byte shall indicate "no synchronization action". In this case, and when framing mode 1 is used, the sc7-0 shall always be coded "$XX0011XX_2$", with X discretionary. When sc0 is set to 1, the LEX byte shall carry AOC. When sc0 is set to 0, the LEX byte shall be coded 00_{16}. The sc0 may be set to 0 only in between transmissions of 5 concatenated and identical AOC messages.

7.4.3 Reduced overhead framing

The format described in 7.4.1.2 for full overhead framing includes overhead to allow for the synchronization of seven ASx and LSx bearer channels. When the synchronization function described in 7.4.2 is not required, the ADSL equipment may operate in a reduced overhead mode. This mode retains all the full overhead mode functions except synchronization control. When using the reduced overhead framing, the framing structure shall be as defined in 7.4.3.1 or 7.4.3.2.

7.4.3.1 Reduced overhead framing with separate fast and sync bytes

The AEX and LEX bytes shall be eliminated from the ADSL frame format, and both the fast and sync bytes shall carry overhead information as described in 7.4.1.2. The fast byte carries the fast buffer CRC, indicator bits, and EOC messages, and the sync byte carries the interleave buffer CRC and AOC messages. The assignment of overhead functions to fast and sync bytes when using the full overhead framing and when using the reduced overhead framing with separate fast and sync bytes shall be as shown in Table 7-5.

In the reduced overhead framing with separate fast and sync bytes, the structure of the fast data buffer shall be as shown in 7.4.1.2.1 with A_F and L_F set to "0". The structure of the interleaved data buffer shall be as shown in 7.4.1.2.2 with A_I and L_I set to "0".

Table 7-5/G.992.1 – Overhead functions for framing modes

Frame Number	Full Overhead Mode		Reduced Overhead Mode	
	Fast Sync	**Interleave Sync**	**Fast Sync**	**Interleave Sync**
0	fast CRC	interleaved CRC	fast CRC	interleaved CRC
1	IB0-7	sync or AOC	IB0-7	AOC
34	IB8-15	sync or AOC	IB8-15	AOC
35	IB16-23	sync or AOC	IB16-23	AOC
all other frames	sync or EOC	sync or AOC	sync or EOC (Note)	AOC
NOTE – In the reduced overhead mode, only "no synchronization action" code shall be used.				

7.4.3.2 Reduced overhead framing with merged fast and sync bytes

In the single latency mode, data is assigned to only one data buffer (fast or interleaved). If data is assigned to only the fast buffer, then only the fast byte shall be used to carry overhead information. If data is assigned to only the interleave buffer, then only the sync byte shall be used to carry overhead information. Reduced overhead framing with merged fast and sync bytes shall not be used when operating in dual latency mode.

For ADSL systems transporting data using a single data buffer (fast or interleaved), the CRC, indicator, EOC and AOC function shall be carried in a single overhead byte assigned to separate data frames within the superframe structure. The CRC remains in frame 0 and the indicator bits in frames 1, 34 and 35. The AOC and EOC bytes are assigned to alternate pairs of frames. For ADSL equipment operating in single latency mode using the reduced overhead framing with merged fast and sync bytes, the assignment of overhead functions shall be as shown in Table 7-6.

In the single latency mode using the reduced overhead framing with merged fast and sync bytes, only one data buffer shall be used. If the fast data buffer is used, the structure of the fast data buffer shall be as shown in 7.4.1.2.1 (with A_F and L_F set to "0") and the interleaved data buffer shall be empty (no sync byte and $K_I = 0$). If the interleaved data buffer is used, the structure of the interleaved data buffer shall be as shown in 7.4.1.2.2 (with A_I and L_I set to "0") and the fast data buffer shall be empty (no fast byte and $K_F = 0$).

Table 7-6/G.992.1 – Overhead functions for reduced overhead mode – with merged fast and sync bytes

Frame Number	(Fast Buffer Only) Fast Byte format	(Interleaved Buffer Only) Sync Byte format
0	Fast CRC	Interleaved CRC
1	IB0-7	IB0-7
34	IB8-15	IB8-15
35	IB16-23	IB16-23
4n+2, 4n+3 with n = 0...16, n ≠ 8	EOC or sync (Note)	EOC or sync (Note)
4n, 4n+1 with n = 0...16, n ≠ 0	AOC	AOC
NOTE – In the reduced overhead mode, only the "no synchronization action" code shall be used.		

7.5 Scramblers

The binary data streams output (LSB of each byte first) from the fast and interleaved data buffers shall be scrambled separately using the following algorithm for both:

$$d'_n = d_n \oplus d'_{n-18} \oplus d'_{n-23} \tag{7-15}$$

where d_n is the n-th output from the fast or interleaved buffer (i.e. input to the scrambler), and d'_n is the n-th output from the corresponding scrambler. This is illustrated in Figure 7-10.

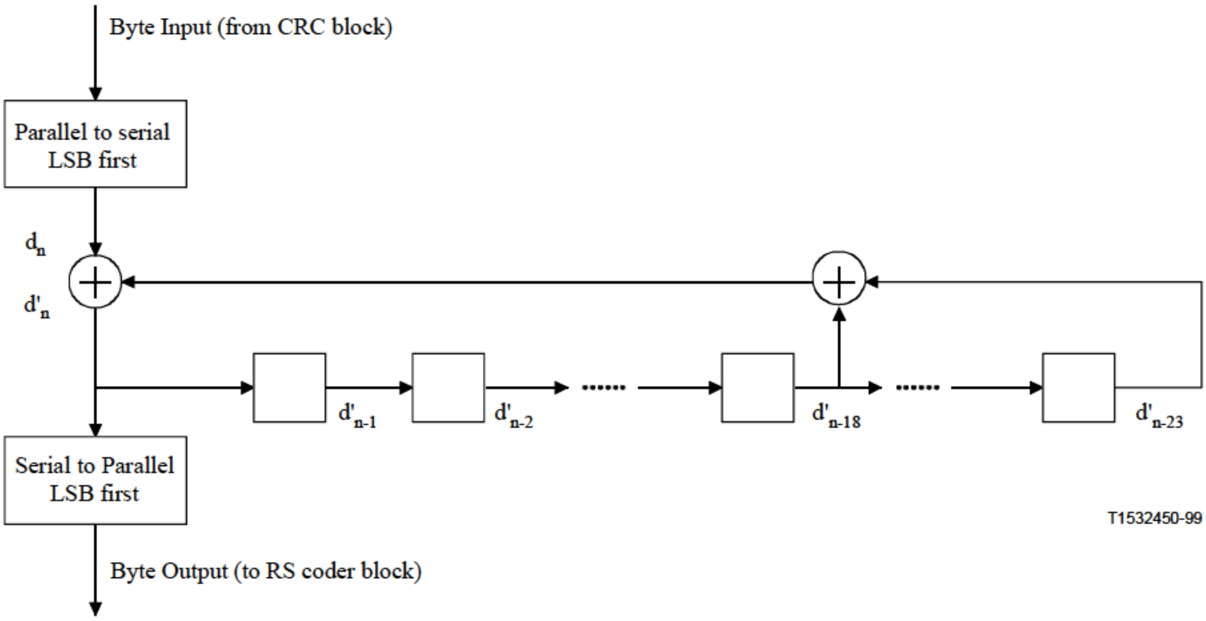


Figure 7-10/G.992.1 – Scrambler

These scramblers are applied to the serial data streams without reference to any framing or symbol synchronization. Descrambling in receivers can likewise be performed independent of symbol synchronization.

7.6 Forward error correction

The ATU-C shall support downstream transmission with at least any combination of the FEC coding capabilities shown in Table 7-7.

Table 7-7/G.992.1 – Minimum FEC coding capabilities for ATU-C

Parameter	Fast buffer	Interleaved buffer
Parity bytes per R-S codeword	R_F = 0, 2, 4, 6, 8, 10, 12, 14, 16 (Note 1)	R_I = 0, 2, 4, 6, 8, 10, 12, 14, 16 (Notes 1 and 2)
DMT symbols per R-S codeword	S = 1	S = 1, 2, 4, 8, 16
Interleave depth	Not applicable	D = 1, 2, 4, 8, 16, 32, 64
NOTE 1 – R_F can be > 0 only if K_F > 0, and R_I can be > 0 only if K_I > 0.		
NOTE 2 – R_I shall be an integer multiple of S.		

The ATU-C shall also support upstream transmission with at least any combination of the FEC coding capabilities shown in Table 8-3.

7.6.1 Reed-Solomon coding

R (i.e. R_F or R_I) redundant check bytes c_0 , c_1, ..., c_{R-2}, c_{R-1} shall be appended to K (i.e. K_F or S $\times K_I$) message bytes m_0, m_1, ..., m_{K-2}, m_{K-1} to form a Reed-Solomon codeword of size $N = K + R$ bytes. The check bytes are computed from the message byte using the equation:

$$C(\mathrm{D}) = M(\mathrm{D})\ \mathrm{D}^{\mathrm{R}} \text{ modulo } G(\mathrm{D}) \tag{7-16}$$

where:

$$M(\mathrm{D}) = m_0\ \mathrm{D}^{\mathrm{K}-1} + m_1\ \mathrm{D}^{\mathrm{K}-2} + ... + m_{\mathrm{K}-2}\ \mathrm{D} + m_{\mathrm{K}-1} \tag{7-17}$$

is the message polynomial,

$$C(\mathrm{D}) = c_0\ \mathrm{D}^{\mathrm{R}-1} + c_1\ \mathrm{D}^{\mathrm{R}-2} + ... + c_{\mathrm{R}-2}\ \mathrm{D} + c_{\mathrm{R}-1} \tag{7-18}$$

is the check polynomial, and

$$G(D) = \prod_{i=0}^{R-1}\left(D + \alpha^{\mathrm{i}}\right) \tag{7-19}$$

is the generator polynomial of the Reed-Solomon code, where the index of the product runs from $i = 0$ to R–1. That is, C(D) is the remainder obtained from dividing M(D) D^{R} by G(D). The arithmetic is performed in the Galois Field GF(256), where α is a primitive element that satisfies the primitive binary polynomial $x^8 + x^4 + x^3 + x^2 + 1$. A data byte (d_7, d_6, ..., d_1, d_0) is identified with the Galois Field element $d_7\alpha^7 + d_6\alpha^6$ ... $+ d_1\alpha + d_0$

The number of check bytes R, and the codeword size N vary, as explained in 7.4.

7.6.2 Reed-Solomon Forward Error Correction Superframe Synchronization

When entering the SHOWTIME state after completion of Initialization and Fast Retrain, the ATU shall align the first byte of the first Reed-Solomon codeword with the first data byte of DF 0.

7.6.3 Interleaving

The Reed-Solomon codewords in the interleave buffer shall be convolutionally interleaved. The interleaving depth varies, as explained in 7.4, but shall always be a power of 2. Convolutional

interleaving is defined by the rule:

Each of the *N* bytes B_0, B_1, ..., B_{N-1} in a Reed-Solomon codeword is delayed by an amount that varies linearly with the byte index. More precisely, byte D_i (with index i) is delayed by (D–1) × *i* bytes, where D is the interleave depth.

An example for $N = 5$, $D = 2$ is shown in Table 7-8, where Bj_i denotes the *i*-th byte of the *j*-th codeword.

Table 7-8/G.992.1 – Convolutional interleaving example for *N* = 5, *D* = 2

Interleaver input	Bj_0	Bj_1	Bj_2	Bj_3	Bj_4	$Bj{+}1_0$	$Bj{+}1_1$	$Bj{+}1_2$	$Bj{+}1_3$	$Bj{+}1_4$
Interleaver output	Bj_0	$Bj{-}1_3$	Bj_1	$Bj{-}1_4$	Bj_2	$Bj{+}1_0$	Bj_3	$Bj{+}1_1$	Bj_4	$Bj{+}1_2$

With the above-defined rule, and the chosen interleaving depths (powers of 2), the output bytes from the interleaver always occupy distinct time slots when *N* is odd. When *N* is even, a dummy byte shall be added at the beginning of the codeword at the input to the interleaver. The resultant odd-length codeword is then convolutionally interleaved, and the dummy byte shall then be removed from the output of the interleaver.

7.6.4 Support of higher downstream bit rates with *S* = 1/2 (optional)

With a rate of 4000 data frames per second and a maximum of 255 bytes (maximum RS codeword size) per data frame, the ADSL downstream line rate is limited to approximately 8 Mbit/s per latency path. The line rate limit can be increased to about 16 Mbit/s for the interleaved path by mapping two RS codewords into one FEC data frame (i.e. by using $S = 1/2$ in the interleaved path). $S = 1/2$ shall be used in the downstream direction only over bearer channel AS0. Support of $S = 1/2$ is optional.

When the K_I data bytes per interleaved mux data frame cannot be packed into one RS codeword, i.e. K_I is such that $K_I + R > 255$, the K_I data bytes shall be split into two consecutive RS codewords. When K_I is even, the first and second codeword have the same length $N_I1 = N_I2 = (K_I/2 + R_I)$, otherwise the first codeword is one byte longer than the second, i.e. first codeword has $N_I1 = (K_I + 1)/2 + R_I$ bytes, the second codeword has $N_I2 = (K_I – 1)/2 + R_I$ bytes. For the FEC output data frame, $N_I = N_I1 + N_I2$, with $N_I < 511$ bytes.

The convolutional interleaver requires all codewords to have the same odd length. To achieve the odd codeword length, insertion of a dummy (not transmitted) byte may be required. For $S = 1/2$, the dummy byte addition to the first and/or second codeword at the input of the interleaver shall be as in Table 7-9.

Table 7-9/G.992.1 –Dummy byte insertion at interleaver input for *S* = 1/2

N_Id1	N_Id2	Dummy Byte Insertion Action
Odd	Odd	No action
Even	Even	Add one dummy byte at the beginning of both codewords
Odd	Even	Add one dummy byte at the beginning of the second codeword
Even	Odd	Add one dummy byte at the beginning of the first codeword and two dummy bytes at the beginning of the second codeword [the de-interleaver shall insert one dummy byte into the de-interleaver matrix on the first byte and the (D + 1)th byte of the corresponding codeword to make the addressing work properly]

7.7 Tone ordering

A DMT time-domain signal has a high peak-to-average ratio (its amplitude distribution is almost Gaussian), and large values may be clipped by the digital-to-analogue converter. The error signal caused by clipping can be considered as an additive negative impulse for the time sample that was clipped. The clipping error power is almost equally distributed across all tones in the symbol in which clipping occurs. Clipping is therefore most likely to cause errors on those tones that, in anticipation of a higher received SNR, have been assigned the largest number of bits (and therefore have the densest constellations). These occasional errors can be reliably corrected by the FEC coding if the tones with the largest number of bits have been assigned to the interleave buffer.

The numbers of bits and the relative gains to be used for every tone shall be calculated in the ATU-R receiver, and sent back to the ATU-C according to a defined protocol (see 10.9.14). The pairs of numbers are typically stored, in ascending order of frequency or tone number i, in a bit and gain table.

The "tone-ordered" encoding shall first assign the $8 \times N_F$ bits from the fast data buffer (see 7.4) to the tones with the smallest number of bits assigned to them, and then the $8 \times N_I$ bits from the interleave data buffer to the remaining tones.

All tones shall be encoded with the number of bits assigned to them; one tone may therefore have a mixture of bits from the fast and interleaved buffers.

The ordered bit table b'_i shall be based on the original bit table b_i as follows:

For $k = 0$ to 15 {

From the bit table, find the set of all i with the number of bits per tone $b_i = k$

Assign b_i to the ordered bit allocation table in ascending order of i

}

A complementary de-ordering procedure should be performed in the ATU-R receiver. It is not necessary, however, to send the results of the ordering process to the receiver because the bit table was originally generated in the ATU-R, and therefore that table has all the information necessary to perform the de-ordering.

Figures 7-11 and 7-12 show an example of tone ordering and bit extraction (without and with trellis coding respectively) for a 6-tone DMT case, with $N_F = 1$ and $N_I = 1$ for simplicity.

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(54) **MULTI-SESSION ASYMMETRIC DIGITAL SUBSCRIBER LINE BUFFERING AND SCHEDULING APPARATUS AND METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/479,611**

(22) Filed: **Jan. 7, 2000**

(51) **Int. Cl.**[7] **H04B 1/38**; H04L 5/16

(52) **U.S. Cl.** **370/395.5**; 370/466; 370/480; 375/222

(58) **Field of Search** 370/230, 235, 370/235.1, 395.1, 412, 428, 429, 395.5, 480, 503, 505, 511, 512, 513, 514, 516; 375/222

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(57) **ABSTRACT**

A transceiver for an asymmetric communication system is provided that implements a buffering and scheduling scheme that utilizes a virtual clock signal to synchronize processing of asynchronous frame data for multiple ADSL sessions. In every virtual clock cycle, the transceiver first sequentially performs transmit-processes for each active ADSL line and then sequentially performs receive-processes for each active ADSL line. An Asynchronous Transfer Mode (ATM) Accelerator provides the network interface to multiple ATM channels and communicates frame data to a Frame Buffer (FB). The FB may be used in a ping-pang fashion for the communication of data between the ATM accelerator and a Framer/Coder/Interleaver (FCI), which performs its namesake, among other, functions. The FCI also interfaces a Digital Signal Processing (DSP) core through an Interleave/De-Interleave Memory (IDIM). The DSP core generates the virtual clock signal, which schedules operation of the ATM accelerator and the FCI. IDIM holds DMT frames of data and may also be utilized in a ping-pang fashion. Memory is shared by multiple ADSL sessions and by the transmit and receive processes within an individual session.

26 Claims, 2 Drawing Sheets

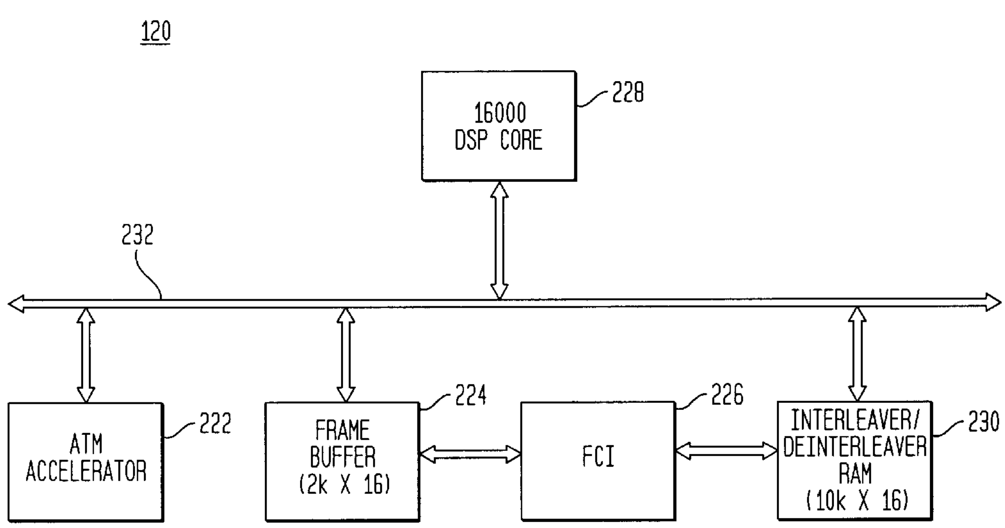


FIG. 1

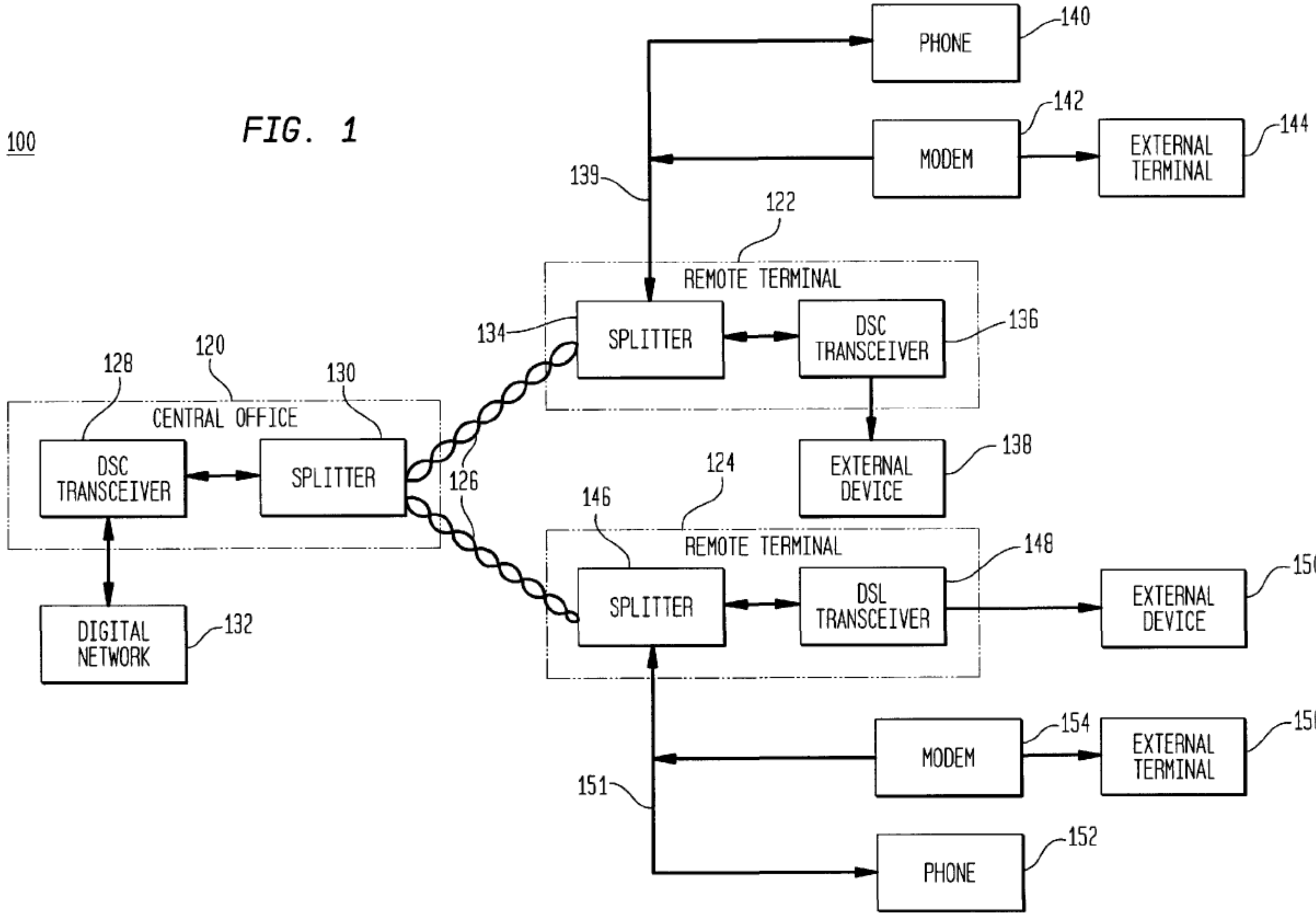

100
CENTRAL OFFICE
DSC TRANSCEIVER
SPLITTER
DIGITAL NETWORK
REMOTE TERMINAL
SPLITTER
DSC TRANSCEIVER
EXTERNAL DEVICE
PHONE
MODEM
EXTERNAL TERMINAL
REMOTE TERMINAL
SPLITTER
DSL TRANSCEIVER
EXTERNAL DEVICE
MODEM
EXTERNAL TERMINAL
PHONE
120
122
124
126
128
130
132
134
136
138
139
140
142
144
146
148
150
151
152
154
156

FIG. 2

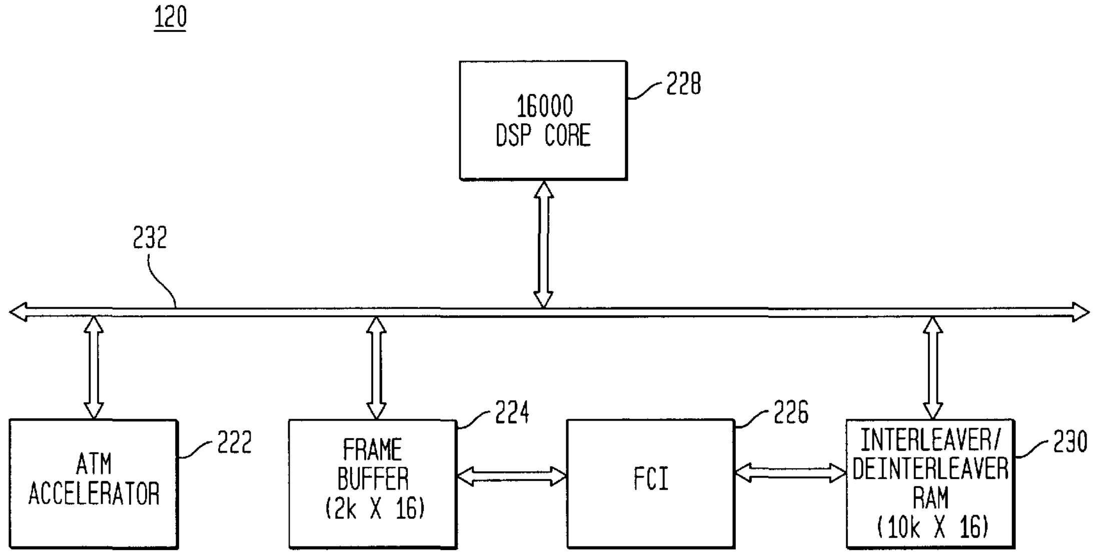
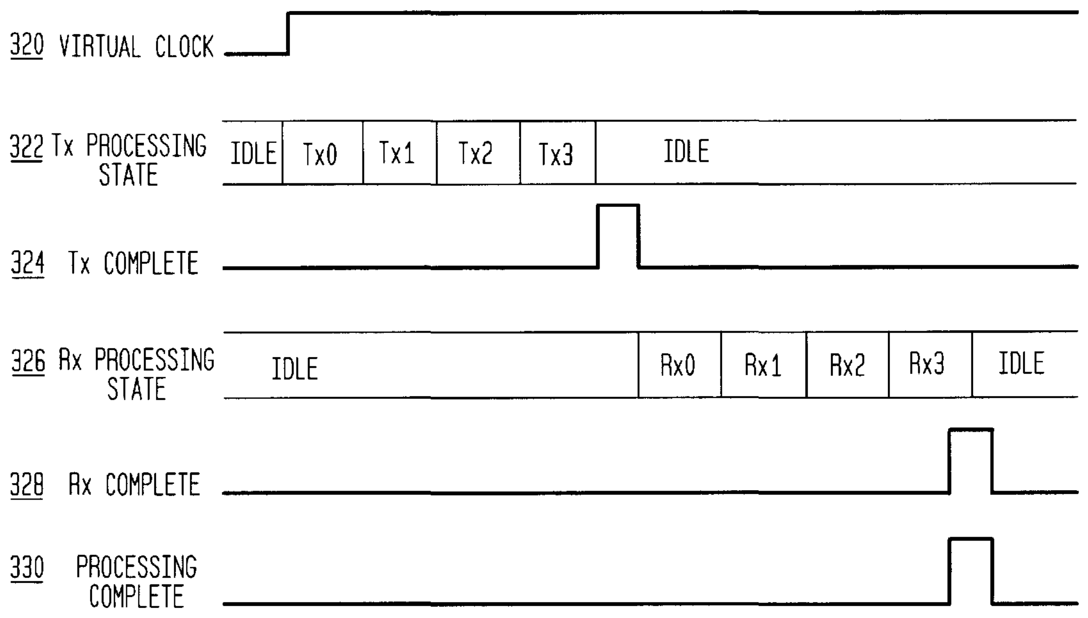

120
16000
DSP CORE
228
232
ATM
ACCELERATOR
222
FRAME
BUFFER
(2k X 16)
224
FCI
226
INTERLEAVER/
DEINTERLEAVER
RAM
(10k X 16)
230

FIG. 3


320 VIRTUAL CLOCK
322 Tx PROCESSING STATE
IDLE
Tx0
Tx1
Tx2
Tx3
IDLE
324 Tx COMPLETE
326 Rx PROCESSING STATE
IDLE
Rx0
Rx1
Rx2
Rx3
IDLE
328 Rx COMPLETE
330 PROCESSING COMPLETE

MULTI-SESSION ASYMMETRIC DIGITAL SUBSCRIBER LINE BUFFERING AND SCHEDULING APPARATUS AND METHOD

FIELD OF THE INVENTION

The invention relates generally to broadband communications, and more particularly to the transmission of broadband signals using twisted-pair cable.

BACKGROUND

High-speed data communications paths are desirable for Internet access and are essential for high data rate interactive services such as video on demand. Since fiber optic cable, the preferred transmission media for such services, is not readily available in the transmission link between a network node and a user premise and is prohibitively expensive to install, it is desirable to utilize the existing Plain Old Telephone Service (POTS) infrastructure. However, current POTS wiring connections consist of copper twisted-pair media which was designed for low frequency, voice-band (0–3400 Hz) analog telephony, and does not readily support the data rates or bandwidth required for high data rate interactive services. Conventional POTS analog transmission is limited to a data rate of about 56 Kbps, which represents only a small portion of the amount of information that can be transmitted over twisted-pair media.

DSL (Digital Subscriber Line) provides a method of communicating high-bandwidth data over twisted-pair media. In addition, some forms of DSL service (e.g., ADSL) include a subdivision of the DSL bandwidth so that some bandwidth is used to provide POTS service simultaneously with data transmission. Thus, DSL enables high data rate interactive services without requiring the installation of fiber optic cable.

Asymmetrical Digital Subscriber Line (ADSL (ANSI T 1.413-1998)) is specifically designed to exploit the asymmetric nature of most multimedia communication, in which large amounts of information flow toward an end user (i.e., downstream) and only a small amount of information (e.g., interactive control information) is returned by the end user to a central office (i.e., upstream). ADSL is "asymmetric" in that most of its two-way (duplex) bandwidth is utilized to transmit downstream and only a small portion is utilized for upstream transmission. Using ADSL, approximately 6–8 Mbps of data can be sent downstream and approximately 512 Kbps can be sent upstream. Other variations of DSL (i.e., xDSL) include High bit rate DSL (HDSL) and Very high bit rate DSL (VDSL).

Many DSL technologies require that a signal splitter be installed at a remote end user location to split POTS service from the digital data transmission. However, the line split for an end user can be managed remotely from a central office using G.Lite (a/k/a DSL Lite, splitterless ADSL, and Universal ADSL), which is essentially a slower form of ADSL. Equipment installation costs are saved using G.Lite (ITU-T standard G-992.2), which provides a data rate of approximately 1.5 Mbps downstream and approximately 512 Kbps upstream.

In a conventional ADSL communication system, an ADSL transceiver at each end of a twisted-pair (a remote end user premise and a central office) connects to the twisted-pair circuit, creating information channels—a high speed downstream channel, a medium speed upstream channel, and depending on implementation, a POTS or an Integrated Services Digital Network (ISDN) channel. Each channel can

be sub-multiplexed to form multiple, lower rate channels utilizing one of several modulation technologies. One such modulation technology, Discrete MultiTone (DMT), is a multi-carrier technique that divides the available bandwidth of twisted-pair media connections into mini-subchannels or bins. In the ADSL standard, DMT may be used to generate up to 250 separate 4.3125 Khz subchannels from 26 Khz to 1.1 Mhz for downstream transmission and up to 26 subchannels from 26 Khz to 138 Khz for upstream transmission. Other modulation technologies used with ADSL include Carrierless Amplitude Modulation (CAP) and Multiple Virtual Line (MVL).

At the central office in a typical ADSL system, a Digital Subscriber Line Access Multiplexer (DSLAM) multiplexes/de-multiplexes a unique set of data for each of multiple ADSL lines, concentrating the ADSL lines into a single terminating device for connection onto the backbone network interconnecting central offices. An ADSL transceiver associated with each ADSL line is in communication with the DSLAM. For the unique data stream of each ADSL line, the ADSL transceiver provides data to (and receives data from) several channels with the data grouped into frames that include both payload data bytes and overhead data bytes. Data from each channel is placed in different positions in a frame depending on whether the data is interleaved or non-interleaved. In general, for transmission, a frame is assembled from the payload data of the channels with overhead bytes appended as appropriate. In particular, a cyclic redundancy check (CRC), scramble, interleave (if selected), and forward error correction (FEC) are performed on the frame data prior to its transmission. The frames in turn are grouped together into a "superframe" which includes 68 data frames plus an additional synchronization frame, which delineates the superframe boundary. A CRC is performed on all the data in a superframe and transmitted in the overhead bytes of the first frame of the next superframe. The frame data is converted into a set of complex symbols, each of which represents a number of frame bits as defined by a bit allocation table. These complex symbols are subsequently converted into an analog signal that is transmitted on a twisted-pair. Conversely, when receiving an analog signal from a twisted-pair, an ADSL transceiver must convert the analog signal into complex digital symbols, convert the complex symbols into a receive frame, and de-interleave, FEC, CRC, and de-scramble the received frame to recover payload data.

In order to provide service to multiple remote end user premises, the central office of an ADSL communication system needs to support multiple ADSL lines, each line having a session or active period of data transfer. In addition, the central office must manage asynchronous downstream and upstream data streams for each ADSL session since, the recurrence of frames containing data for/from an individual remote end user is not necessarily periodic. In a conventional ADSL communication system, the central office has an ADSL transceiver for each remote end user served by the system. Such a system is excessively duplicative in terms of transceivers and memory in each transceiver, and thus more costly than necessary to provide the desired functionality.

SUMMARY OF THE INVENTION

The invention provides an Asymmetric Digital Subscriber Line (ADSL) transceiver that manages multiple asynchronous ADSL sessions, synchronizing the digital signal processing tasks for the sessions with a buffering and scheduling scheme such that the various transceiver components operate seamlessly (i.e., in a semi-synchronous fashion).

Utilizing this buffering and scheduling methodology, reductions in the design sizes of various transceiver components and the data flow complexity of the transceiver may be achieved.

A central office transceiver (i.e., headend processor) according to the invention includes various functional elements and memories coupled together with digital signal processing tasks synchronized by a virtual clock signal. An Asynchronous Transfer Mode (ATM) Accelerator provides the network interface to multiple ATM channels for multiple asynchronous ADSL sessions. The ATM accelerator transfers frame data to a Frame Buffer (FB) as controlled by a Digital Signal Processing (DSP) core. The FB provides a dual access memory that is used in a ping-pang fashion, based on the logic level of the virtual clock, for the communication of data between the ATM accelerator and a Framer/Coder/Interleaver (FCI). The FCI performs various processing tasks on the frame data and also interfaces the DSP core through an Interleave/De-interleave Memory (IDIM), which holds DMT frames of data and may also be utilized in a ping-pang fashion. The DSP core generates the virtual clock signal, which is approximately 4 Khz and coincides with the ADSL Discrete MultiTone (DMT) symbol rate. The DSP core controls operation of the ATM accelerator and the FCI and performs various processing tasks such as moving data to/from the FB and the IDIM.

According to the buffering and scheduling scheme of the invention, after every transition of the virtual clock signal (i.e., in every virtual clock cycle), the transceiver first steps through ADSL lines, performing FCI transmit-processes for each active ADSL line and generating a control signal after completing all transmit-processes. The FCI then again steps through ADSL lines, processing receive-processes for all active ADSL lines and generating control signals indicating completion of receive processes and completion of all processing.

In every virtual clock cycle, the DSP core provides the FCI with data by reading Receive (RX) data frames to and loading Transmit (TX) data frames from the FB after processing. The FB is divided into segments for each individual ADSL session with the same memory space used for both RX data and TX data. The FCI and ATM accelerator first perform reading processes and then loading processes, reading RX data first before loading the TX data into the FB. In this way, the same buffer can be used for both RX data and TX data, thereby permitting the FB memory to be half the size of that in a conventional ADSL transceiver arrangement. The DSP core also loads RX data frames and reads TX data frames to/from the IDIM, which may be used in a ping-pang fashion by the FCI and DSP core.

Numerous other advantages and features of the present invention will become readily apparent from the following detailed description of the invention and the embodiments thereof, from the claims and from the accompanying drawings in which details of the invention are fully and completely disclosed as a part of this specification.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference may be had to the following Detailed Description of exemplary embodiments thereof, considered in conjunction with the accompanying drawings, in which:

FIG. **1** illustrates, in block diagram form, an Asymmetric Digital Subscriber Line (ADSL) system/in accordance with the invention;

FIG. **2** illustrates, in block diagram form, an ADSL transceiver for a central office in accordance with the invention;

FIG. **3** illustrates, an exemplary processing sequencing for a case when four Transmit and Receive lines are enabled;

In the detailed description below, like reference numerals are used to describe the same, similar or corresponding elements in FIGS. **1**–**3**.

DETAILED DESCRIPTION

A headend transceiver (i.e., central office side processor) is provided for processing Asymmetric Digital Subscriber Line (ADSL) data. The provided ADSL transceiver implements a buffering and scheduling scheme for synchronizing the digital signal processing tasks for multiple asynchronous ADSL lines. As a result, the various components of the ADSL transceiver are able to operate seamlessly (i.e., in a semi-synchronous fashion) and the design sizes of various transceiver components and the data flow complexity of the transceiver are reduced. It should be noted, however, that the ADSL transceiver of the invention may alternatively incorporate other variations of DSL (i.e., xDSL), such as High bit-rate DSL (HDSL) and Very high bit-rate DSL (VDSL).

Asymmetric Digital Subscriber Line Communication System

FIG. **1** illustrates, in block diagram form, an Asymmetric Digital Subscriber Line (ADSL) system in accordance with the invention. The ADSL system **100** includes a central office **120** and remote end user terminals 122–124, which are connected together copper twisted-pair media forming a telephone line **126**. The central office **120** includes an ADSL transceiver according to the invention **128** and a splitter **130**. Central office ADSL transceiver **128** is bi-directionally coupled to the splitter **130** and is additionally bi-directionally coupled externally to a digital network **132**.

A first remote end user terminal **122** includes splitter **134** and conventional ADSL transceiver **136**. ADSL transceiver **136** is bi-directionally coupled to splitter **134** and is additionally coupled to external device **138**. The splitter **134** is bi-directionally coupled via a Plain Old Telephone Service (POTS) channel **139** to a telephone **140** and is additionally coupled to a modem **142**. The modem **142** is further coupled to an external terminal **144**. The second remote end user terminal **124** is similarly arranged. The second remote end user terminal **124** includes a splitter **146** and a conventional ADSL transceiver **148**. The ADSL transceiver **148** is bi-directionally coupled to the splitter **146** and is additionally coupled to an external device **150**. The splitter **146** is bi-directionally coupled via a POTS channel **151** to a telephone **152** and additionally coupled to a modem **154**, which is further coupled to an external terminal **156**.

The exemplary digital communication system **100** allows high-speed data communication between a variety of remote end users having computers, telephones, fax machines, modems, television sets, and any number of other communication devices. Digital network **132** is used to transmit information for a variety of high data rate interactive services, each of which may have a different transmission format and frequency. An exemplary digital communication system employing G.lite is similar to FIG. **1**, with splitters **130**, **134** and **146** merely replaced by a hardware device providing a direct correction to ADSL transceivers **128**, **136**, and **148** respectively.

Central Office ADSL Transceiver

FIG. **2** illustrates a central office ADSL transceiver **120** according to the invention. The transceiver implements a

buffering and scheduling scheme for synchronizing the processing of data on multiple ADSL lines (i.e., sessions), thereby enabling the various components of the transceiver to operate seamlessly (i.e., in a semi-synchronous fashion). In conventional ADSL, data arrives at and is transmitted by the ADSL transceiver asynchronously. The data is asynchronous in the sense that the recurrence of frames containing information to/from an individual end-user are not necessarily periodic. In addition, frame data does not necessarily arrive at the transceiver synchronous with a transition in a transceiver clock; the transceiver clock may not coincide with the start of any frame of data. Therefore, frame data must be buffered in order to make frame data for each ADSL line available for processing on a transition of a transceiver clock. The transceiver of the invention buffers and schedules these asynchronous communications for multi-session ADSL, synchronizing digital signal processing tasks utilizing an approximately 4 Khz virtual clock of the same frequency as the ADSL Discrete MultiTone (DMT) symbol rate. This buffering and scheduling scheme permits reductions in the design size of transceiver components and the data flow complexity of the transceiver.

The ADSL transceiver of the invention **120** is a single integrated circuit which has various component including: an Asynchronous Transfer Mode (ATM) accelerator **222**, a Frame Buffer (FB) **224**, a Framer/Coder/Interleaver (FCI) **226**, a Digital Signal Processing (DSP) core **228**, and a Interleave/De-Interleave Memory (IDIM) **230**. The FCI **226** interfaces the ATM accelerator **222** through the FB **224** and interfaces the DSP core **228** through the IDIM **230**. Transceiver components that interface each other may be bi-directionally coupled via a bus **232**, which refers to a plurality of signals or conductors which may be used to transfer one or more various types of information, such as data, address, control, or status information. In a preferred embodiment, the bus **232** is a sixteen bit bus. A virtual clock signal of approximately 4 Khz, which coincides with the ADSL DMT symbol rate, is generated by the DSP core **228** and controls the operation of the ATM accelerator **222** and FCI **226**.

The Asynchronous Transfer Mode (ATM) accelerator **222** is the network interface to multiple ATM channels (not shown). The ATM accelerator provides those functions that are responsible for data transport for a plurality of data streams communicated via twisted pair media. The data may be transported on any one of a plurality of programmable bearer channels. The data is synchronized into an appropriate one of the plurality of programmable bearer channels and the channels multiplexed in the ATM accelerator as determined by the ADSL standard. The ATM accelerator subjects this framed data to various operations that calculate a plurality of complex numbers representing DMT tones. The ATM accelerator subsequently transfers this DMT tone data on the twisted-pair media. In exemplary embodiments, the ATM accelerator may include UTOPIA-2 and serial port external network interface elements.

The Frame Buffer (FB) **224** provides a dual access memory that is used in a ping-pang fashion to transfer unframed bearer channel data between the ATM accelerator **222** and the FCI **226**. "Ping-pang" means that areas of the memory buffer are alternately utilized exclusively by one agent (a transceiver component for performing some function) and then by a second agent. As one area of memory is being used by a first agent, another area of memory can be used by a different agent. As long as different agents (in this case, the ATM accelerator and the FCI) access different areas of a dual access memory, there are no memory address conflicts that could cause communication errors. At any time, an agent is allowed to access either a ping area of memory or a pang area of memory based on the logic level of the virtual clock signal. Thus, the FB should be allocated a memory of a size sufficient to provide ping-pang functionality. In the preferred embodiment as illustrated in FIG. **2**, the frame buffer is allocated as two 1 K×16 memory blocks, since the smallest Random Access Memory (RAM) block currently available is 1 K×16.

The Framer/Coder/Interleaver (FCI) **226** interfaces the ATM accelerator **222** through the FB **224**. The FCI Supports multiple ADSL sessions and performs various tasks on payload data including: framing/de-framing, cyclic redundancy check generation/checking (CRCing), scrambling/de-scrambling, Reed-Solomon encoding/decoding, and interleaving/de-interleaving. The FCI may also provide Network Timing Reference generation and insertion, Interleave and Fast Path support, and access to its internal state and data in support of a test methodology using the DSP core as smart test controller. All functionalities of the FCI are provided as per ADSL standards. In a preferred embodiment of the invention, approximately four G.lite (ITU G.992.2) or approximately four ADSL (ANSI T1.413-1998) sessions are supported by the FCI. It should be noted that the FCI is able to support additional sessions limited only by the size of the buffers with which it is interconnected and not limited to any specific implementation.

The Digital Signal Processing (DSP) core **228** generates a virtual clock signal that controls the operation of the ATM accelerator **222** and the FCI **226**. The virtual clock signal is an approximately 4 Khz signal that coincides with the ADSL DMT symbol rate. The DSP core **228** also responds to control signals generated by the ATM accelerator **222** and FCI **226** and performs various tasks such as moving data to/from the FB **224** and the IDIM **230**. The DSP core may access the other components of the transceiver through a standard memory read/write operation. Alternatively, the components of the transceiver of the invention need not necessarily be co-located on a single computer chip. In that case the DSP core may access other transceiver components via a programmable (Direct Memory Access) DMA channels. DMA allows data to be sent directly from an attached device to the a processor's memory

In the exemplary embodiment, the transceiver uses a Digital Signal Processor (DSP) core and is preferably implemented as a core of an DSP16K single chip DSP, which is available from Lucent Technologies, Inc., of Murrary Hill, N.J. it should be noted, however, that other types of processor cores may also be utilized for the DSP core. According to the invention, processing components of the transceiver communicate with the DSP core. Other processing elements having additional functionality may be added to the transceiver as needed and implemented as peripheral modules to the DSP core. Thus, the invention is not limited to the particular components disclosed herein.

The Interleave/De-Interleave Memory (IDIM) **230** provides a memory through which the FCI **226** interfaces the DSP core **228**. The IDIM holds DMT frames of data and may be utilized in a ping-pang fashion. The IDIM is used to transfer framed, coded and possibly interleaved data frames between the FCI core and the DSP Core. In addition to interleave data storage, the IDIM may contain a dedicated area for the transfer of fast path data to the DSP Core. The IDIM may be organized as 16 bit words with byte write capability to allow beneficial performance of various interleave/de-interleave processes.

In a preferred embodiment of the invention, the IDIM is allocated as 10 K×16 (i.e., 20 K) Random Access Memory

(RAM), which supports approximately four G.lite or approximately four standard ADSL session/s at less than full interleave depth. The size of the IDIM and the interleave depth may be varied so that a different number of sessions may be supported by the transceiver of the invention. The size of the IDIM is derived as follows. A simple implementation of a transmit interleaver for G.lite communication requires 4 Kbytes per session for downstream processing, derived by multiplying the maximum codeword length by the maximum interleaver depth. The simple G.lite transmit interleaver also requires 2 Kbytes per session for upstream processing. Therefore, 24 Kbytes of RAM is required to support four G.lite sessions. Similarly, a simple implementation of a transmit interleaver for standard ADSL requires 16 Kbytes per session for downstream processing and 2 Kbytes per session for upstream processing, for a total of 72 Kbytes for four sessions. A fast path buffer is also required for fast path data in both the interleave and de-interleave processes and requires 256 bytes of RAM per session, or a total of 1 K bytes for four sessions. Since the smallest RAM block currently available is 1 K×16, 1 K×16or 2 Kbytesmust be allocated for the fast path buffer per direction. Therefore, a simple implementation of an interleaver would require 76 Kbytes for four standard ADSL sessions (64 K interleave +8 K de-interleave +4 K fast path). An optimal implementation of the interleaver according to the method of the invention utilizes the same memory for receive data and transmit data and thus requires 20 Kbytes to support a standard ADSL session at full interleave depth (16 K interleave & de-interleave +4 K fast path). With a lesser interleave depth, additional sessions may be supported with the same size buffer. With a larger buffer, additional session may be supported.

It should be noted that in a preferred embodiment, the firmware required for performing processing tasks associated with the central office is resident on the single integrated circuit transceiver of the invention. As functions implemented in hardware are typically executed more quickly than those implemented in software, for optimal speed, central office transceiver of the invention implements its functions in hardware so that data is transmitted at a high rate. It should be noted, however, that similar functionality can be provided in a software implementation.

Buffering and Scheduling Scheme

To provide ADSL service, normal operation of the ADSL transceiver of the invention requires that, in every virtual clock cycle, the DSP core provide the FCI with data by reading one or more frames of Receive (RX) data from the FB (Frame Buffer) and loading one or more frames of Transmit (TX) data to the FB. In addition, the DSP core needs to load one or more frames of RX data to the IDIM and read one or more frames of TX data from the IDIM.

FIG. **3** depicts an exemplary processing sequence according to the invention for a case when four ADSL lines are enabled (i.e., four sessions are active). FCI processing is initiated by a transition of the virtual clock signal **320**. Logic within the FCI captures the state of the virtual clock signal on successive CLK rising edges to detect the transition. Virtual clock signal transitions are generated by the DSP Core at an approximately 4 KHz rate (i.e., approximately 69/68*4 KHz), locked to the modem frame rate and local timing reference. According to the buffering and scheduling scheme of the invention, after every transition of the virtual clock signal (i.e., in every virtual clock cycle), the FCI core first processes TX data for each active ADSL line **322** (reading from the FB, framing, CRCing, scrambling, encoding and interleaving). After processing TX data, the FCI core then processes RX data for each active ADSL line **326** (deinterleavilg, decoding, CRCing, descrambling, and deframing, writing to the FB). This sequence of operations minimizes memory requirements by allowing the RX data to overwrite the same memory area in the FB that is used by the TX data, thereby permitting the size of the FB to be half that of a conventional ADSL transceiver. Since buffers/memory space consume integrated circuit area and add to the cost of a device, the memory savings and corresponding reduction in buffer size permitted by the invention reduces integrated circuit area and ADSL transceiver cost. In addition, since the single transceiver sequentially performs processing for multiple ADSL sessions, a central office that utilizes the ADSL transceiver of the invention consistently requires a lesser number of ADSL transceivers than prior art ADSL communications systems. While described in terms of an ADSL transceiver, the buffering and scheduling scheme of the invention may also be utilized in transceivers for various xDSL communication systems including High bit-rate DSL (HDSL) and Very high bit rate DSL (VDSL).

In a given virtual clock processing cycle, the stream processing state machine (i.e., FCI) will first begin processing TX data. The FCI will step through each TX line in increasing order, testing for enabled lines and initiating a TX processing state for a line as required **322**. If a TX line is not enabled, the FCI immediately evaluates the next TX line. After evaluating all TX lines and processing all enabled TX lines, the FCI signals the DSP core that all TX processes are complete (TX_Complete **324**). Note that, because of the processing cycle operation, all TX lines are modem frame aligned when a processing cycle is complete and TX line data resides in the IDIM.

Once TX processes are complete, the FCI begins processing RX data. The FCI steps through each RX lines in increasing order, testing for enabled lines and initiating a RX processing state for a line as required **326**. If an RX line is not enabled, the FCI immediately evaluates the next RX line. After evaluating all RX lines and processing all enabled RX lines, the FCI signals the DSP core that all RX processes are complete (RX_Complete **328**) and that all processing is complete (Processing_Complete **330**). Note that, because of the processing cycle, all RX Lines must be modem frame aligned when placed in the IDIM for processing by the FCI. The DSP core may require additional memory to perform this alignment, which may have some impact on overall RX path latency. In every DMT symbol cycle (i.e., virtual clock cycle), the FCI will load the FB, which is divided into segments for each individual ADSL session, with received data after receiver processing. The same memory space in the FB is used for both RX data and TX data. The FCI and the ATM accelerator always start the reading process and then the loading process. That is, the ATM accelerator reads RX data first before loading the TX data into the frame buffer. In this way, the same buffer can be used for both RX data and TX data, thereby permitting the size of the FB to be half that of a conventional ADSL transceiver arrangement.

The IDIM may also be used in a ping-pang fashion by the FCI and the DSP core based on the virtual clock cycle. For example, between the events of the virtual clock signal transition and the rising edge of the TX processes are complete signal (TX_Complete **324**), the DSP core may load new DMT frames of RX data to a portion of the IDIM used as de-interleave memory while the FCI is using a portion of the IDIM as interleave memory. Between the events of TX_Complete **324** and signal that all RX processes are complete (RX_Complete **328**), the DSP core can

read TX data from the portion of the IDIM used as interleave memory while FCI is accessing the portion of the IDIM used as de-interleave memory.

Conclusion

There has been described and illustrated herein, an method and apparatus for synchronizing the asynchronous data processing tasks for multiple Asymmetric Digital Subscriber Line (ADSL) sessions using a single ADSL transceiver. The headend ADSL transceiver of the invention implements a buffering and scheduling scheme such that various transceiver components operate seamlessly (i.e., in a semi-synchronous fashion) and share memory. Based on a virtual clock signal that coincides with the DMT symbol rate, the transceiver steps through all ADSL lines and processes receive tasks. After completing receive tasks, the transceiver, steps through all ADSL lines and processes transmit tasks. Thus, the same memory may be used by each of multiple ADSL sessions and by both transmit processes and receive processes. Thus, a lesser number of transceivers, each transceiver utilizing a lesser amount of memory, may be used to implement an ADSL communication system according to the invention.

It is to be understood that the invention is not limited to the illustrated and described forms and embodiments contained herein. It will be apparent to those skilled in the art that various changes using different configurations and functionally equivalent components and programming may be made without departing from the scope of the invention. Thus, the invention is not considered limited to what is shown in the drawings and described in the specification and all such alternate embodiments are intended to be included in the scope of this invention as set forth in the following claims.

What is claimed is:

1. A digital subscriber line (DSL) transceiver for a plurality of DSL sessions, said DSL transceiver comprising:

an asynchronous transfer mode (ATM) accelerator interfacing a plurality of ATM channels for each of said plurality of DSL sessions, said ATM accelerator operative to convert a first analog signal to a first bit stream, said ATM accelerator operative to convert a second bit stream, said ATM accelerator operative to convert a second bit stream to a second analog signal;

a frame memory bi-directionally coupled to said ATM accelerator, said frame memory operative to receive a bit stream and store said bit stream as a frame of data;

a framer/coder/interleaver (FCI) bi-directionally coupled to said frame memory, said FCI operative to perform a data operation on said frame of data;

an interleave/de-interleave memory (IDIM) bi-directionally coupled to said FCI, said IDIM operative to receive said frame of data and store said frame of data; and

a digital signal processing (DSP) core for performing a processing task, said DSP core bi-directionally coupled to said ATM accelerator, said frame memory and said IDIM,

wherein said DSP core includes a means to generate a periodic signal, wherein, responsive to said periodic signal, said transceiver performs a transmit process sequentially for a first subset of said plurality of DSL sessions and performs a receive process sequentially for a second subset of said plurality of DSL sessions.

2. The DSL transceiver of claim **1**, wherein said periodic signal is generated at a frequency of 69/68×4 KHz.

3. The transceiver of claim **1**, wherein said data operation performed by said FCI is selected from the group consisting of framing, de-framing, error checking, scrambling, de-scrambling, encoding, de-coding, interleaving and de-interleaving.

4. The transceiver of claim **1**, wherein said FCI further includes

a means for framing/de-framing said frame of data;

a means for error check generation and evaluation of said frame of data;

a means for scrambling/de-scrambling said frame of data;

a means for encoding/de-coding said frame of data; and

a means for interleaving/de-interleaving said frame of data.

5. The DSL transceiver of claim **1**, wherein said FCI further includes:

a means for performing a transmit process sequentially for a first subset of said plurality of DSL sessions;

a means for generating a first signal indicating said transmit process for said first subset of said plurality of DSL sessions has been performed;

a means for performing a receive process sequentially for a second subset of said plurality of DSL sessions; and

a means for generating a second signal indicating said receive process for said second subset of DSL sessions has been performed.

6. The DSL transceiver of claim **1**, wherein said FCI further includes

a means for generating and inserting a network timing reference;

a means providing interleave and fast path support; and

a means providing access to internal state and data of said FCI.

7. The DSL transceiver of claim **1**, wherein said DSP core includes

a means to move said bit stream between said ATM accelerator and said frame memory;

a means to move said frame of data to said IDIM.

8. The DSL transceiver of claim **1**, wherein said frame memory operates in a ping-pang fashion based on said periodic signal.

9. The DSL transceiver of claim **1**, wherein said frame memory is a RAM of a size that supports at least two of said frames of data and operates in a ping-pang fashion.

10. The DSL transceiver of claim **1**, wherein said IDIM further includes a fast path memory.

11. The DSL transceiver of claim **1**, wherein said IDIM operates in a ping-pang fashion based on said periodic signal.

12. The DSL transceiver of claim **1**, wherein said IDIM is a RAM of a size that supports at least four full depth G.lite sessions or approximately one full depth standard ADSL session.

13. The DSL transceiver of claim **1**, wherein each of said plurality of DSL sessions supported by said DSL transceiver is XDSL selected from the group consisting of asymmetric DSL (ADSL), High bit-rate DSL (HDSL), and Very high bit rate DSL (VDSL).

14. The DSL transceiver of claim **1**, wherein each of said plurality of DSL sessions supported by said DSL transceiver is modulated according to a modulation technology selected from the group consisting of Discrete Multitone, Carrierless Amplitude Modulation, and Multiple Virtual Line.

15. A method of buffering and scheduling for a multi-session digital subscriber line (DSL) transceiver, said

method comprising the steps of generating a periodic signal, said periodic signal having a rising edge and a declining edge;

responsive to said rising edge of said periodic signal, sequentially performing a transmit process for each of a first plurality of DSL sessions, said transmit process utilizing a first memory;

generating a first signal indicative of a completion of said transmit process for said first plurality of DSL sessions;

responsive to said first signal, sequentially performing a receive process for a second plurality of DSL sessions, said receive process utilizing a second memory; and

generating a second signal indicative of a completion of said receive process for said second plurality of DSL sessions.

16. The method of buffering and scheduling of claim **15** wherein said first memory and said second memory are the same.

17. The method of buffering and scheduling of claim **16** wherein said first memory and said second memory are operated in a ping-pang fashion based on a state of said periodic signal.

18. A digital subscriber line (DSL) transceiver for transmitting and receiving data for a plurality of DSL sessions, said DSL transceiver composing:

an asynchronous transfer mode (ATM) accelerator interfacing a plurality of asynchronous transfer mode channels for each of a plurality of DSL sessions, said ATM accelerator including a means to perform a first transmit process and a means to perform a first receive process on frame data;

a frame buffer for holding said frame data;

a framer/coder/interleaver (FCI) interfacing said ATM accelerator through said frame buffer, said FCI including a means to perform a second transmit process and a means to perform a second receive process on said frame data;

an interleave/de-interleave memory (IDIM); and

a digital signal processing (DSP) core interfacing said FCI through said IDIM, said DSP core including a means to perform a third transmit process and a means to perform a third receive process on said frame data;

wherein said first transmit process, said second transmit process and said third transmit process are characterized as transmit processing, and said first receive process, said second receive process and said third receive process are characterized as receive processing; and

wherein said DSP core includes a means to generate a periodic signal, said periodic signal operative to initiate a performance of transmit processing sequentially for a first subset of said plurality of DSL sessions and a performance of a receive processing sequentially for a second subset of said plurality of DSL sessions.

19. The DSL transceiver of claim **18**, wherein said periodic signal is generated at a frequency of 69/68×4 Khz.

20. The DSL transceiver of claim **18**, wherein said first transmit process converts a first bit stream to a first analog signal and said first receive process converts a second analog signal to a second bit stream.

21. The DSL transceiver of claim **18**, wherein said second transmit process is selected from the group consisting of framing, error check generation, scrambling, encoding, and interleaving.

22. The DSL transceiver of claim **18**, wherein said second receive process is selected from the group consisting of de-framing, error check evaluation, de-scrambling, de-coding and de-interleaving.

23. The DSL transceiver of claim **18**, wherein said third transmit process and said third receive process comprises moving said frame data.

24. A DSL transceiver of claim **18**, wherein said frame buffer is a RAM buffer operated in a ping-pang fashion based on said periodic signal.

25. A DSL transceiver of claim **18**, wherein said IDIM is a RAM buffer operated in a ping-pang fashion based on said periodic signal.

26. A DSL transceiver of claim **18**, wherein said IDIM is a RAM buffer sized to support at least four full depth G.lite sessions or approximately one full depth standard ADSL session.

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medium interface connector (MIC) A connector interface at which signal transmit and receive characteristics are specified for attaching stations and concentrators. One class of MICs is the connection between the attaching stations and the lobe cabling. A second set is the attachment interface between the concentrator and its lobes. A third set is the interface between the concentrator and the trunk cabling. Two types of connectors are specified: one for connecting to STP media and one for connecting to UTP media. (C/LM) 8802-5-1998

medium ion (dc electric-field strength and ion-related quantities) Ion comprised of several molecules or molecular clusters bound together by charge that is larger and less mobile than a small ion due to more mass or a greater number of molecular clusters. Typical radius is in the range of 10^{-9} m to 2×10^{-8} m. Mobility is in the range of 10^{-7} m^2/Vs to 10^{-5} m^2/Vs. (T&D/PE) 539-1990, 1227-1990r

medium noise (sound recording and reproducing system) The noise that can be specifically ascribed to the medium. *See also:* noise. 191-1953w

medium-pulse-repetition-frequency waveform A pulsed-radar waveform whose pulse-repetition frequency (PRF) is such that targets of interest are ambiguous with respect to both range and Doppler shift. *See also:* high-pulse-repetition-frequency waveform; low-pulse-repetition-frequency waveform. (AES) 686-1997

medium scale integration (MSI) (A) Pertaining to an integrated circuit containing between 100 and 500 transistors in its design. *Contrast:* large scale integration; very large scale integration; small scale integration; ultra-large scale integration. **(B)** Pertaining to an integrated circuit containing between 10 and 100 elements. (C) 610.10-1994

medium voltage (1) (cable systems in power generating stations) 601 to 15 000 V. (PE/EDPG) 422-1977
(2) (system voltage ratings) A class of nominal system voltages greater than 1000 V and less than 100 000 V. *See also:* low voltage; nominal system voltage; high voltage. (IA/PSE/APP) 241-1990r, [80]

medium-voltage aluminum-sheathed power cable (aluminum sheaths for power cables) Cable used in an electric system having a maximum phase-to-phase rms ac voltage above 1 000 V to 72 500 V, the cable having an aluminum sheath as a major component in its construction. (PE/IC) 635-1989r

medium-voltage power cable (1) (cable systems in power generating stations) Cables designed to supply power to utilization devices of the plant auxiliary system, operated at 601 to 15 000 V. (PE/EDPG) 422-1977
(2) Cable designed to supply power to utilization devices of the plant auxiliary system, operated at 5000–46 000 V in sizes ranging from 8 AWG (8.37 mm^2) to 2000 kcmil (1010.0 mm^2). (PE/IC) 1185-1994

medium-voltage system (electric power for industrial and commercial systems only) An electric system having a maximum root-mean-square alternating-current voltage above 1000 volts to 72 500 volts. *See also:* voltage classes. (IA/PSE) 570-1975w

meet *See:* AND.

meg Colloquial reference for megabyte. (C) 610.10-1994w

mega (M) (A) (mathematics of computing) A prefix indicating one million (10^6). **(B) (mathematics of computing)** In statements involving size of computer storage, a prefix indicating 2^{20}, or 1 048 576. (C) 1084-1986

megabyte Either 1 000 000 bytes or 2^{20} bytes. *Notes:* 1. The user of these terms shall specify the applicable usage. If the usage is 2^{10} or 1024 bytes, or multiples thereof, then note 2 below shall also be included with the definition. 2. As used in IEEE Std 610.10-1994, the terms kilobyte (kB) means 2^{10} or 1024 bytes, megabyte (MB) means 1024 kilobytes, and gigabyte (GB) means 1024 megabytes. *See also:* gigabyte. (C) 610.10-1994w

megacycle One million cycles. (C) 610.10-1994w

megahertz (MHz) (1) A unit of frequency equal to 1 000 000 cycles per second. (LM/C) 802.7-1989r
(2) A unit of frequency equal to 1 000 000 Hz, that is, 10^6 Hz. (C) 610.7-1995

Meissner oscillator An oscillator that includes an isolated tank circuit inductively coupled to the input and output circuits of an amplifying device to obtain the proper feedback and frequency. *See also:* oscillatory circuit. (AP/ANT) 145-1983s

mel A unit of pitch. By definition, a simple tone of frequency 1000 hertz, 40 decibels above a listener's threshold, produces a pitch of 1000 mels. *Note:* The pitch of any sound that is judged by the listener to be *n* times that of the 1-mel tone is *n* mels. (SP) [32]

melting channel The restricted portion of the charge in a submerged resistor or horizontal-ring induction furnace in which the induced currents are concentrated to effect high energy absorption and melting of the charge. *See also:* induction heating. (IA) 54-1955w, 169-1955w

melting-speed ratio (1) The ratio between between 0.1 s and 300 s or 600 s minimum melting currents, whichever is specified, which designates the relative speed of the fuse link. (SWG/PE) C37.40-1993
(2) (of a fuse) A ratio of the current magnitudes required to melt the current-responsive element at two specified melting times. *Notes:* 1. Specification of the current wave shape is required for time less than one-tenth of a second. 2. The lower melting time in present use is 0.1 s, and the higher minimum melting current times are 100 a for low-voltage fuses and 300 s or 600 s, whichever specified, for high-voltage fuses. (SWG/PE) C37.100-1992

melting time (1) (protection and coordination of industrial and commercial power systems) The time required to melt the current-responsive element on a specified overcurrent. Where the fuse is current limiting in less than half-cycle, the melting time may be approximately half or less of the clearing time. (IA/PSP) 242-1986r
(2) (of a fuse) The time required for overcurrent to sever the current-responsive element. (SWG/PE/SWG-OLD) C37.100-1992, C37.40-1993, C37.40b-1996

member In data management, a subunit contained in a partitioned data set. (C) 610.5-1990w

membrane keyboard A type of keyboard in which the keys are not raised, rather it is composed of a semi-flexible plastic sheet with a conductive surface below. *Synonym:* pressure-sensitive keyboard. (C) 610.10-1994w

membrane potential The potential difference, of whatever origin, between the two sides of a membrane. *See also:* electrobiology. (EMB) [47]

memory (1) All of the addressable storage in a processing unit and other internal storage that is used to execute instructions. *See also:* main storage. (C) 610.10-1994w
(2) *See also:* storage medium; storage.

memory action (of a relay) A method of retaining an effect of an input after the input ceases or is greatly reduced, so that this input can still be used in producing the typical response of the relay. *Note:* For example, memory action in a high-speed directional relay permits correct response for a brief period after the source of voltage input necessary to such response is short-circuited. (PE) C37.100-1992

memory address An address of a particular storage location in memory. (C) 610.10-1994w

memory address register A register containing the address of the memory location to be accessed. (C) 610.10-1994w

memory agent A module that uses split transactions to assume all the rights and responsibilities of some number of remote memory modules. (C/BA) 896.4-1993w

memory allocation and protection (A) To allocate physical sections of memory into logical partitions with read/write protection provided within each partition. **(B)** Pertaining to the hardware components that perform the allocation as in (A). (C) 610.10-1994

ties in the practical application of the definition of occupied bandwidth; in such cases a different percentage may be useful. (EMC) C63.4-1988s

occurrence An individual instance of an entity, record, or item, containing a specific set of values for its constituent parts. (C) 610.5-1990w

OCR *See:* optical character reader; optical character recognition.

OCR-A *See:* optical character recognition-A.

OCR-B *See:* optical character recognition-B.

octad (mathematics of computing) (octade) A group of three bits used to represent one octal digit. (C) 1084-1986w

octal (A) (mathematics of computing) Pertaining to a selection in which there are eight possible outcomes. **(B) (mathematics of computing)** Pertaining to the numeration system with a radix of eight. (C) 1084-1986

octal character string A sequence of characters from the set of octal digits the first of which shall be the digit zero. Octal character strings shall consist only of the following characters:

0 1 2 3 4 5 6 7

Within software definition files of exported catalogs, all such strings shall be encoded using IRV. (C/PA) 1387.2-1995

octal digit A numeral used to represent one of the eight digits in the octal numeration system; 0, 1, 2, 3, 4, 5, 6, or 7. (C) 1084-1986w

octal notation Any notation that uses the octal digits and the radix 8. (C) 1084-1986w

octal number (A) A quantity that is expressed using the octal numeration system. **(B)** Loosely, an octal numeral. (C) 1084-1986

octal number system* *See:* octal numeration system.

* Deprecated.

octal numeral A numeral in the octal numeration system. For example, the octal numeral 14 is equivalent to the decimal numeral 12. (C) 1084-1986w

octal numeration system The numeration system that uses the octal digits and the radix 8. *Synonym:* octal system. (C) 1084-1986w

octal point The radix point in the octal numeration system. (C) 1084-1986w

octal system *See:* octal numeration system.

octal-to-binary conversion The process of converting an octal numeral to an equivalent binary numeral. For example, octal 213.2 is converted to binary 10001011.01. (C) 1084-1986w

octal-to-decimal conversion The process of converting an octal numeral to an equivalent decimal numeral. For example, octal 213.2 is converted to decimal 139.25. (C) 1084-1986w

octant *See:* sextant.

octantal error (navigation) (navigation aid terms) An error in measured bearing caused by the finite spacing of the antenna elements in systems using spaced antennas to provide bearing information (such as VOR [very high-frequency omnidirectional range]): this error varies in a sinusoidal manner throughout the 360° and has four positive and four negative maximums. (AES/GCS) 172-1983w

octary tree A tree of order 8. *Note:* Such a tree is typically used to store three-dimensional data. *Synonyms:* octonary tree; octtree. (C) 610.5-1990w

octave (1) (data transmission) In electric communication, the interval between two frequencies having a ratio of 2 to 1. (PE) 599-1985w

(2) The interval between two frequencies that have a frequency ratio of 2 (e.g., 1 to 2 Hz, 2 to 4 Hz, 4 to 8 Hz, etc.). (SWG/PE/T&D/PSR) C37.98-1977s, 539-1990, C37.100-1992, C37.81-1989r

(3) **(overhead power lines)** The interval between two sounds having a fundamental frequency ratio of two. (T&D/PE) 539-1990

octave band, one-third octave band The integrated sound pressure level of all components in a frequency band corresponding to a specified octave. *Note:* The location of an octave band pressure level on a frequency scale, f_0, is usually specified as the geometric mean of the upper and lower frequencies of the octave. The lower frequency of the octave band is $f_0/\sqrt{2}$ and the upper frequency is $(/\sqrt{2})f_0$. A third-octave band extends from a lower frequency $f_0/{}^6/\sqrt{2}$ to an upper frequency of $({}^6/\sqrt{2})f_0$. (T&D/PE) 656-1992

octave-band pressure level (1) (octave pressure level) (sound) The band pressure level for a frequency band corresponding to a specified octave. *Note:* The location of an octave-band pressure level on a frequency scale is usually specified as the geometric mean of the upper and lower frequencies of the octave. (SP/ACO) [32]

(2) **(overhead power lines)** The integrated sound pressure level of all components in a frequency band corresponding to a specified octave. *Note:* The location of an octave band pressure level on a frequency scale, f_0, is usually specified as the geometric mean of the upper and lower frequencies of the octave. The lower frequency of the octave band is $f_0/{}^6/\sqrt{2}$ and the upper frequency is $({}^6/\sqrt{2})f_0$. A third-octave band extends from a lower frequency $f_0/{}^6/\sqrt{2}$ to an upper frequency of $({}^6/\sqrt{2})f_0$. (T&D/PE) 539-1990

octet (1) A group of eight adjacent binary digits operated on as a unit. (SUB/PE/C) 999-1992w, 610.5-1990w, 1084-1986w

(2) A sequence of eight bits, usually operated upon as a unit. (DIS/C) 1278.1-1995

(3) A data unit composed of eight ordered binary bits. An octet is encoded as a pair of code symbols. (C/LM) 802.9a-1995w

(4) A byte composed of eight bits. (LM/C) 802.3u-1995s, 610.10-1994w

(5) An ordered sequence of 8 b. *Note:* Octets can be stored in larger objects if appropriate to a particular architecture. (C/PA) 1224-1993w, 1327-1993w

(6) An eight-bit data entity (byte). (C/MM) 1284.1-1997

(7) 8 b data object. *See also:* byte. (PE/SUB) 1379-1997

(8) A group of 8 bits, also known as a byte. (IM/ST) 1451.2-1997

(9) A sequence of eight bits. (AMR/SCC31) 1377-1997

(10) A bit-oriented element that consists of eight contiguous binary bits. (C/LM/CC) 8802-2-1998

(11) Unit of data representation that consists of eight contiguous bits. (C) 1003.5-1999

(12) A group of eight adjacent bits. (EMB/MIB) 1073.4.1-2000, 1073.3.2-2000

Octet Array A value of type `OctetArray`. (IM/ST) 1451.1-1999

octet string (1) A value of ASN.1 type octetstring. (C/PA) 1238.1-1994w

(2) A string composed of octets. (C/PA) 1328-1993w, 1327-1993w, 1224-1993w

octetstring type A simple type whose distinguished values are an ordered sequence of zero, one or more octets, each octet being an ordered sequence of 8 bits. (C/PA) 1238.1-1994w

octlet (1) A set of eight adjacent bytes. (C/BA) 10857-1994, 896.3-1993w, 896.4-1993w

(2) Eight bytes of data. (MM/C) 1394-1995, 1596-1992

(3) Eight bytes (64 bits) of data. Not to be confused with an "octet," which has been used to describe 8 bits of data. In this document, the term **byte,** rather than "octet," is used to describe 8 bits of data. (C/MM) 1754-1994

(4) An ordered set of eight adjacent bytes. (C/BA) 1014.1-1994w

(5) An 8-byte data format or data type. Not to be confused with an octet, which has been commonly used to describe 8 bits of data. In this document, the term byte, rather than octet, is used to describe 8 bits of data. (C/MM) 1596.5-1993

(6) Eight bytes of data. Not to be confused with an octet, which has been commonly used to describe eight bits of data.

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Martin H. Weik

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setting up an operation for execution. The timing pulses are also called clock pulses and the program timing matrix a clock-pulse generator.

matrix printer—See *printer, matrix.*

matrix switch—Same as *matrix* (*2*).

maximal—Pertaining to the most, greatest, largest, highest, longest, or similar superlative. (Contrast with *minimal.*)

MDE—An abbreviation for Magnetic Decision Element. (Further clarified by *element, logic.*)

mean entropy, character—See *entropy, character mean.*

mean repair time—Same as *mean-time-to-repair.*

mean-time-between-failures—The limit of the ratio of operating time of equipment to the number of observed failures as the number of failures approaches infinity. Abbreviated MTBF. (Contrast with *mean-time-to-failure.*)

mean-time-to-failure—The average or mean time between initial operation and the first occurrence of a failure or malfunction, as the number of measurements of such time on many pieces of identical equipment approaches infinity. Abbreviated MTTF. (Contrast with *mean-time-between-failures.*)

mean-time-to-repair—The average time required to accomplish corrective maintenance. (Abbreviated MTTR. Synonymous with *mean repair time.*)

mean transinformation content—See *content, mean transinformation.*

measure, information—A function of the frequency of occurrence of a specified event from a set of possible events. The term event is to be understood as used in probability theory. An event might be the occurrence or presence of a given element in a set, or the occurrence of a specified character or word in a given position of a message.

measurement, work—A method of establishing a relationship between the quantity and quality of work performed and the man and machine power utilized.

mechanical dictionary—Same as *dictionary, automatic.*

mechanical differential analyzer—See *analyzer, mechanical differential.*

mechanical language—Same as *language, artificial.*

mechanical replacement—See *replacement, mechanical.*

mechanical translation—See *translation, mechanical.*

mechanized—Same as *readable, machine.*

mechanized data—Same as *data, machine-readable.*

medium—A material or method for storing or otherwise handling data; for example, magnetic cores, paper tape, magnetic tape, punched cards, microfiche, laser emulsion, delay-lines, and microfilm. These data carriers provide for storage, mobility, and transportability of data. (Synonymous with *data medium.* Further clarified by *carrier, data* and by *medium, input-output.*)

medium, data—**1:** The material may be represented, usually as a physical variable of the medium, that is, the material itself; for example magnetic tape, magnetic cores, punched cards, punched tape, or magnetic discs. **2:** The physical quantity that may be varied to represent data; for example the liquid in a thermometer.

medium, empty—A data medium that does not contain data and usually has a frame of reference enabling it to hold addtional data; for example, a blank form, blank tape, or an unrecorded disc.

medium, input-output—A material substance intended for carrying recorded data and designed to be transportable independently of the reading and writing mechanism; for example, a punched card, a magnetic card, a magnetic tape, paper tape, a paper sheet, preprinted stationery, or microfilm. The medium is handled by an input-output device, such as a card reader-punch, a magnetic tape handler, a paper tape perforator, a high-speed printer, or a camera. The medium is used to insert data and instructions into a computer and to remove results. (Further clarified by *medium* and by *carrier, data.*)

medium, machine-readable—A data medium that can be used to convey data to a sensing device; for example punched cards, punched tapes, and magnetic tapes. (Synonymous with *automated data medium* and with *mechanized data medium.*)

medium, storage—The material, or its configuration, on which data is recorded; for example, paper tape, cards, magnetic cores, magnetic tape, drums, discs, or laser-emulsion.

medium, transfer—A material that transfers a solid or liquid ink during printing, usually consisting of a sheet or ribbon of fabric, paper, or plastic film as a supporting base, with liquid or solid ink absorbed into or coated on the supporting base.

medium, virgin—A data medium in or on which data has not been recorded; for example unmarked paper, paper tape that has no holes in it, or magnetic discs on which no recording has been made.

meet—Same as *AND.*

meet operation—Same as *operation, conjunction.*

megabit—One million binary digits.

megahertz—One million cycles per second.

member, print—See *print-member.*

memory—Same as *storage.*

memory, core-rope—Same as *storage, core-rope.*

memory, Olsen—Same as *storage, core-rope.*

memory, plated-wire—A storage device consisting of an array of elements, each made up of a thin cylindrical shell of electro-deposited magnetic material on a bare copper wire substrate. The memory element is formed by making a coil

operation is performed or executed in response to a single manual command.

step-by-step operation—Same as *operation, single-step.*

step change—See *change, step.*

step counter—See *counter, step.*

step size, plotter—Same as *size, increment.*

stepping register—Same as *register, shift.*

stick, joy—In graphic display systems, a lever that can be moved in at least two dimensions, thereby permitting the control of the movement of one or more display elements or cursors. (Further clarified by *cursor.*)

sticking—The tendency of a bistable device, such as a flip-flop or a switch, to remain in or switch back to a particular one of its two stable states.

stochastic—Pertaining to direct solution by trial-and-error, usually without a step-by-step approach, and involving analysis and evaluation of progress made, as in a heuristic approach to trial-and-error methods. In a stochastic approach to a problem solution, intuitive conjecture or speculation is used to select a possible solution, which is then tested against known evidence, observations or measurements. Intervening or intermediate steps toward a solution are omitted. (Contrast with *algorithm* and *heuristic.*)

stochastic model—See *model, stochastic.*

stop, coded—Same as *halt, programmed.*

stop, form—A device on a machine that stops the machine when the supply of paper has run out.

stop, programmed—Same as *halt, programmed.*

stop bit—See *bit, stop.*

stop element—Same as *bit, stop.*

stop instruction—Same as *instruction, halt.*

stop instruction, optional—Same as *instruction, optional-halt.*

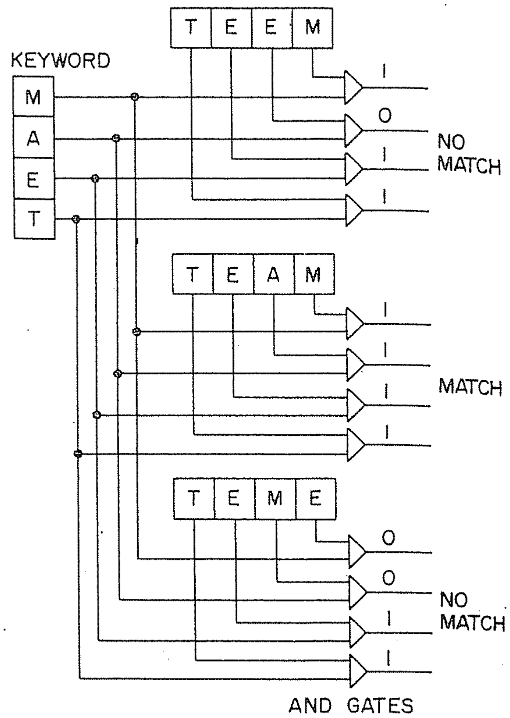
stop signal—Same as *bit, stop.*

storage—1: A device or pertaining to a device which receives data, holds and, at a later time, returns data; for example, a plugboard, an array of magnetic cores, a magnetic disc, an electrostatic storage tube, a delay-line, or a bank of flip-flops. Various phenomena, such as electrostatic, ferroelectric, magnetic, acoustic, optical, chemical, electronic, electrical, mechanical and nuclear, are used to effect storage. (Synonymous with *store,* with *memory,* and with *computer store.*) 2: In computer simulation, a specific piece of equipment in which transactions may be stored.

storage, allocate—To assign specific storage areas for specific purposes, such as holding specific routines, holding input/output data or constants, serving as working storage or scratch-pad storage, holding loading programs or executive routines, and storing priority data. (Further clarified by *allocation, storage.*)

storage, annex—Same as *storage, associative.*

storage, associative—A storage device in which the storage locations are identified by their contents rather than by their names,



All storage locations in the above associative storage unit are queried simultaneously to determine if the given keyword is stored. If a match occurs, the appropriate storage location is identified simultaneously and immediately. Many logic elements are required.

addresses, or relative positions. The associative storage is capable of being interrogated in parallel fashion throughout its entire contents to determine whether or not a given word is stored by directly comparing it with all words stored without regard for addressing. For example, if a file consists of many sets of data elements, each element being the label for a set of allowable data items, such as the case of a personnel file, where each set of data elements pertains to a person, then each set of data elements could be put at an addressed storage location. To search for a data item as a key, such as all captains, all storage locations would have to be read and all data items compared to the key. In associative storage, a parallel-read storage operation would immediately identify and retrieve all the data items in the file that were related to the data item matching the key. In a certain sense, the search key is the address of the sought data. Thus, the associative storage quickly answers the question, "Is this word contained in storage?" If the answer is yes, all data associated with the key word may be transferred out. The concept reduces address bookkeeping, since the keys serve as addresses. Information is retrieved by an associative and parallel process without

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out of the incomplete transaction. This allows you to maintain your database's integrity. You may, however, lose the single transaction you were working on when your network got sick.

Transaction Processing A processing method in which transactions are executed immediately when they are received by the system, rather than at some later time as in batch-processing systems. Airline reservation databases and automatic teller machines are examples of transaction-processing systems.

Transactional Integrity A term that describes how your computing/telecom system handles making sure that the transaction you just made is solid and clean and that the next time you want to get to the results of the transaction you can. "Transactional integrity" becomes critical when you're storing bits and pieces of your transactions on different media, in different places. For example, you might want to store your data on a magnetic hard drive and your associated images on a separate optical drive.

Transborder Data Flow TDF. Transborder data flows are movements of machine-readable data across international boundaries. TDF legislation began in the 1970s and has been put into effect by many countries in an attempt to protect personal privacy of citizens. This term has particular meaning as it relates to electronic commerce or EDI and is becoming more and more relevant with the use of the Internet as a means to conduct global business.

Transceiver 1. Any device that transmits and receives. In sending and receiving information, it often provides data packet collision detection as well.

2. In IEEE 802.3 networks, the attachment hardware connecting the controller interface to the transmission cable. The transceiver contains the carrier-sense logic, the transmit/receive logic, and the collision-detect logic.

3. A device to connect workstations to standard thick Ethernet-style (IEEE 802.3).

Transceiver Cable In local area networks, a cable that connects a network device such as a computer to a physical medium such as an Ethernet network. A transceiver cable is also called drop cable because it runs from a network node to a transceiver (a transmit / receiver) attached to the trunk cable. See Transceiver.

Transcoder A device that combines two 1.544 megabit per second bit streams into a single 1.544 megabit per second bit stream to enable transmission of 44 or 48 voice conversations over a DS-1 medium.

Transcoding A procedure for modifying a stream of data carried so that it may be carried via a different type of network. For example, transcoding allows H.320 video encoding, carried via circuit switched TDM systems to be converted to H.323 so that it can connect with and be transmitted across packet switched ethernet LAN.

Transcriptionist A person who listens to a tape recording and types the words he hears. The word, transcriptionist, derives from the verb to transcribe. The most common employment of transcribers is in the medical industry, where busy doctors talk into tape recorders telling good and bad news of their patients. And even busier transcriptionists type those words into the patient's medical records, or whatever.

Transducer A device which converts one form of energy into another. The diaphragm in the telephone receiver and the carbon microphone in the transmitter are transducers. They change variations in sound pressure (your voice) to variations in electricity, and vice versa. Another transducer is the interface between a computer, which produces electron-based signals, and a fiber-optic transmission medium, which handles photon-based signals.

Transfer A telephone system feature which provides the ability to move a call from one extension to another. It is probably the most commonly used and misused feature on a PBX. Before you buy a PBX, check out how easy it is to transfer a call. If you have a single line phone, you should simply hit the touch hook, hear a dial tone and then dial the chosen extension number and hang up. This sounds easy in principle, but many people find it difficult since they associate the touch hook with hanging up the phone. Some companies have gotten around this by putting a "hook flash" button on the phone itself. Such a button is like having an autodial button which just makes the exact short tone you make when you quickly hit the hook flash button. An even better solution is an electronic phone with a button specially marked "transfer," or a button next to a screen which lights up "transfer." Failing to efficiently transfer a call is the easiest way to give your customers the wrong impression of your firm. Think of how many times have you called a company only to be told it wasn't the fellow's job and he will transfer the call, but "If we get cut off, please call Joe back on extension 2358." There are typically four types of Transfer: Transfer using Hold, Transfer using Conference, and Transfer with and without Announcement.

Transfer Callback A phone system feature. After a specified number of rings, an unanswered transferred call will return to the telephone which originally made the transfer.

Transfer Delay A characteristic of system performance that expresses the time delay in processing information through a data transmission system.

Transfer Impedance A measure of shield effectiveness.

Transfer Mode A fundamental element of a communications protocol, transfer mode refers to the functioning arrangement between transmitting and receiving devices across a network. There are two basic transfer modes: connection-oriented and connectionless. Connection-oriented network protocols require that a call be set up before the data transmission begins, and that the call subsequently be torn down. Further, all data are considered to be part of a data stream. Examples of connection-oriented protocols include analog circuit-switched voice and data, ISDN, X.25 and ATM.

Connectionless protocols, on the other hand, do not depend on such a process. Rather, the transmitting device gains access to the transmission medium and begins to transmit data address to the receiver, without setting up a logical connection across the physical network. LANs (e.g. Ethernet and Token Ring) make use of connectionless protocols, as does SMDS, which actually is an extension of the LAN concept across a MAN (Metropolitan Area Network). For more detail, see Connection Oriented and Connectionless Mode Transmission.

Transfer Protocols Protocols are all of the packaging" that surround actual user data to tell the network devices where to send the data, who it comes from, and how to tell if it arrived. Transfer protocols are designed for the efficient moving of larger chunks of user data.

Transfer Rate The speed of data transfer — in bits, bytes or characters per second — between devices.

Transfer Switch Usually a switch which reverses two input-output combinations.

Transfer Time A power backup term. Transfer time can refer to either the speed to which an off-line UPS transfers from utility power to battery power, or to the speed with which an on-line UPS switches from the inverter to utility power in the event of an inverter failure. In either case the time involved must be shorter than the length of time that the computer's switching power supply has enough energy to maintain adequate output voltage. this hold-up time may range from eight to 16 milliseconds, depending on the point in the power supply's recharging cycle that the power outage occurs, and the amount of energy storage capacitance within the power supply. A transfer time of 4ms is most desirable , however, it should be noted that an oversensitive unit may make unnecessary power transfers.

Transformer Transformers are devices that change electrical current from one voltage to another. A step-up transformer increases the voltage and a step-down transformer decreases voltage. The power of an electric current must be conserved so just as voltage is increased, current is decreased. Transformers work by feeding an alternating current into a primary coil. The primary coil induces a magnetic field in a secondary coil which is connected to an energy using load. The difference between the number of coils in the primary coil versus the secondary coil determines whether the voltage will be stepped up or down. One reason for using a transformer is that commercial power is typically 120 or 240 volts while many phone systems (and other computer-type "things") work best on 48, 24 or lower voltage.

Transformer Exciting Network See TEN.

Transhybrid Loss The transmission loss between opposite ports of a hybrid network, that is between the two ports of the four-wire connection.

Transient Any high-speed, short duration increase or decrease impairment that is superimposed on a circuit. Transients can interrupt or halt data exchange on a network. See HIT.

Transient Mobile Unit A mobile unit communicating through a foreign base station.

Transistor The transistor was invented in 1947 by John Bardeen, Walter H. Brattain and William Shockley of Bell Laboratories. The first transistor comprised a paper clip, two slivers of gold, and a piece of germanium on a crystal plate. Here is an explanation of how a transistor works, taken from "Signals, The Science of Telecommunications" by John Pierce and Michael Noll:

"To understand how a transistor works, we must look at the laws of quantum mechanics. We commonly picture an atom as a positive nucleus surrounded by orbiting electrons ... Vacuum tubes rely on the ability of electrons to travel freely with any energy through a vacuum. Transistors rely on the free travel of electrons through crystalline solids called semiconductors ... Semiconductors (such as silicon or gallium arsenide) differ from pure con-

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point must be reversed (*backed out*) and a DBMS must provide facilities to ensure this happens. When the processing of a transaction has been completed satisfactorily the changes to the database are *committed* – made permanent.

transaction file (movement file) A file, especially a *data file, containing transaction records, prior to the updating of a *master file. Transaction files are only used in *batch processing systems. Once updating has been carried out, the transaction file may be kept in order to permit subsequent recovery of the master file (*see* FILE RECOVERY) or for auditing purposes but is otherwise redundant.

transaction processing A method of organizing a data-processing system in which *transactions are processed to completion as they arise. A *transaction processing monitor* (*TP monitor*) is a software system that facilitates the handling of transactions in such circumstances. *Compare* BATCH PROCESSING.

transceiver A device that can both transmit and receive signals on a communication medium. Many communication devices, including *modems, *codecs, and *terminals, are transceivers.

transducer 1. (sensor) Any device that converts energy in the form of sound, light, pressure, etc., into an equivalent electrical signal, or vice versa. For example, a semiconductor laser converts electrical energy into light, and a piezoelectric device converts mechanical stress into electrical energy (and vice versa).
2. In formal language theory, any *automaton that produces output.

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transfer rate *See* DATA TRANSFER RATE.

transformation 1. *Another name for* function, used especially in geometry.
2. of programs. *See* PROGRAM TRANSFORMATION.
3. of statistics data. A change of scale used to improve the validity of statistical analyses. For data in which small values have smaller *variance than large values a logarithmic or square-root transformation is often recommended. For data in the form of proportions, a transformation from the scale (0,1) to an infinite scale is advisable before performing *analysis of variance or *regression analysis. Several transformations exist for proportions, such as the *logistic or log-odds-ratio that is used in the analysis of *generalized linear models. Appropriate transformations may be suggested by studying *residuals in a regression analysis.

transformational grammar A grammar that makes essential use of transformation rules to convert the *deep structures of sentences into their surface structures. *See also* GENERATIVE GRAMMAR.

transformational semantics *See* PROGRAM TRANSFORMATION.

transformation matrix An $m \times n$ matrix of numbers used to map vectors with n elements onto vectors with m elements.

transformation monoid *See* TRANSFORMATION SEMIGROUP.

transformation semigroup A *semigroup consisting of a collection C of transformations of a *set S into itself (*see* FUNCTION), the *dyadic operation $\circ$ being the *composition of functions; it is essential that the set C should be *closed with respect to composition, i.e. if c_1 and c_2 are in C then so is $c_1 \circ c_2$.
If the identity transformation (*see* IDENTITY FUNCTION) is included in the transformation semigroup, a *transformation monoid* results. Every monoid is isomorphic to a transformation monoid.

transform domain *See* FILTERING.

transient error An error that occurs once or at unpredictable intervals. *See also* ERROR RATE.

transistor A semiconductor device having, in general, three terminals that are attached to electrode regions within the device. Current flowing between two of these electrodes is made to vary in response to voltage or current variations imposed on the third electrode. The device is capable of current or voltage amplification depending on the particular circuit implementation employed. It can also be used as a switch by driving it between its maximum and minimum of current flow.
The transistor was invented in 1948 by Shockley, Brattain, and Bardeen at Bell Telephone Labs. As performance and manufacturing techniques improved, the tran-

Kilobyte

From Wikipedia, the free encyclopedia

The **kilobyte** is a multiple of the unit byte for digital information. The International System of Units (SI) defines the prefix *kilo* as 1000 (10^3); therefore one kilobyte is 1000 bytes.[1] The unit symbol for the kilobyte is **kB**. In information technology, particularly in reference to main memory capacity, *kilobyte* is traditionally used to denote 1024 (2^{10}) bytes. This arises from the powers-of-two sizing common to such memory in digital circuitry. In this context, the symbols **K** and **KB** are often used when 1024 bytes is meant.

Contents

Definitions and usage

1000 bytes

In the International System of Units (SI) the prefix *kilo* means 1000 (10^3); therefore, one kilobyte is 1000 bytes. The unit symbol is kB.

This is the definition recommended by the International Electrotechnical Commission (IEC).[2] This definition, and related definitions of prefixes mega- = 1 000 000, giga- = 1 000 000 000, etc., are used for data transfer rates[3] in computer networks, internal bus, hard drive and flash media transfer speeds, and for the capacities of most storage media, particularly hard drives,[4] flash-based storage,[5] and DVDs. It is also consistent with the other uses of the SI prefixes in computing, such as CPU clock speeds or measures of performance.

The Mac OS X 10.6 file manager is a notable example of this usage in software. Since Snow Leopard, file sizes are reported with decimal prefixes.[6]

One byte is defined by IEC/80000-13 as 8 bits (1 B = bit). Therefore 1 kB = 8000 bit.

1024 bytes

The kilobyte also often refers to 1024 (2^{10}) bytes.[7][8][9] The usage of the metric prefix *kilo* for binary multiples arose as a convenience, because 1000 approximates 1024.[10]

The binary interpretation of metric prefixes is still prominently used by the Microsoft Windows operating system,[11] which is used on 90% of the world's personal computers.[12] They are also used for random-access memory capacities, such as main memory and CPU cache sizes, due to the binary addressing of memory.[a]

It is also used in marketing and billing by some telecommunication companies, such as Vodafone,[13] AT&T,[14] Orange[15] and Telstra.[16]

The binary representation of 1024 bytes typically uses the symbol KB (uppercase *K*). The *B* is often omitted in informal use. For example, a processor with 65,536 bytes of cache might be said to have "64K" of cache.

Kibibyte

In December 1998, the IEC addressed such multiple usages and definitions by creating prefixes such as kibi, mebi, gibi, etc., to unambiguously denote powers of 1024.[17] Thus the kibibyte, symbol KiB, represents $2^{10} = 1024$ bytes. These prefixes are now part of the International System of Quantities. The IEC further specified that the kilobyte should only be used to refer to 1000 bytes. In practice, *kilobyte* is still commonly used to refer to 1024 bytes.

Examples

- The Shugart SA-400 5 ¹⁄₄-inch floppy disk (1976) held 109,375 bytes unformatted,[18] and was advertised as 110 Kbyte, using the 1000 convention.[19] Likewise, the 8-inch DEC RX01 floppy (1975) held 256,256 bytes formatted, and was advertised as 256k.[20] On the other hand, the Tandon 5 ¹⁄₄-inch DD floppy format (1978) held 368,640 (which is 360×1024) bytes, but was advertised as 360 KB, following the 1024 convention.
- On modern systems, all versions of Microsoft Windows including the newest (as of 2015) Windows 10 divide by 1024 and represent a 65,536-byte file as 64 KB.[21] Conversely, Mac OS X Snow Leopard and newer represent this as 66 kB, rounding to the nearest 1000 bytes.[22]

See also

- History of the floppy disk
- Binary prefix
- Timeline of binary prefixes
- Gigabyte § Consumer confusion
- JEDEC memory standards § Unit prefixes for semiconductor storage capacity
- Units of information § Size examples

Notes

a. Exceptions did exist for machines that used decimal addressing, such as the IBM 1401. A "12 K" 1401 has 12,000 characters of memory.

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First Named Inventor	Marcos C. Tzannes			Examiner Name	Pfizenmayer, Mark		

This is a Request for Continued Examination (RCE) under 37 CFR 1.114 of the above-identified application.
Request for Continued Examination (RCE) practice under 37 CFR 1.114 does not apply to any utility or plant application filed prior to June 8, 1995, or to any design application. The Instruction Sheet for this form is located at WWW.USPTO.GOV

SUBMISSION REQUIRED UNDER 37 CFR 1.114

Note: If the RCE is proper, any previously filed unentered amendments and amendments enclosed with the RCE will be entered in the order in which they were filed unless applicant instructs otherwise. If applicant does not wish to have any previously filed unentered amendment(s) entered, applicant must request non-entry of such amendment(s).

☐ Previously submitted. If a final Office action is outstanding, any amendments filed after the final Office action may be considered as a submission even if this box is not checked.

- ☐ Consider the arguments in the Appeal Brief or Reply Brief previously filed on ________
- ☐ Other ________

☒ Enclosed

- ☒ Amendment/Reply
- ☐ Information Disclosure Statement (IDS)
- ☐ Affidavit(s)/ Declaration(s)
- ☐ Other ________

MISCELLANEOUS

☐ Suspension of action on the above-identified application is requested under 37 CFR 1.103(c) for a period of months ________
(Period of suspension shall not exceed 3 months; Fee under 37 CFR 1.17(i) required)

☐ Other ________

FEES

☒ **The RCE fee under 37 CFR 1.17(e) is required by 37 CFR 1.114 when the RCE is filed.**
The Director is hereby authorized to charge any underpayment of fees, or credit any overpayments, to Deposit Account No 191970

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT REQUIRED

☒ Patent Practitioner Signature
☐ Applicant Signature

Doc code: RCEX
Doc description: Request for Continued Examination (RCE)

PTO/SB/30EFS (07-09)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Signature of Registered U.S. Patent Practitioner			
Signature	/Jason H. Vick/	Date (YYYY-MM-DD)	2009-12-17
Name	Jason H. Vick	Registration Number	45285

This collection of information is required by 37 CFR 1.114. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.

2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.

3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.

4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).

5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.

6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).

7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.

8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.

9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Electronic Patent Application Fee Transmittal

Application Number:	11246163
Filing Date:	11-Oct-2005
Title of Invention:	Resource sharing in a telecommunications environment
First Named Inventor/Applicant Name:	Marcos C. Tzannes
Filer:	Jason Vick/Joanne Vos
Attorney Docket Number:	5550-54

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
Request for continued examination	1801	1	810	810
		Total in USD ($)		**810**

Electronic Acknowledgement Receipt

EFS ID:	6661680
Application Number:	11246163
International Application Number:	
Confirmation Number:	5478
Title of Invention:	Resource sharing in a telecommunications environment
First Named Inventor/Applicant Name:	Marcos C. Tzannes
Customer Number:	62574
Filer:	Jason Vick/Joanne Vos
Filer Authorized By:	Jason Vick
Attorney Docket Number:	5550-54
Receipt Date:	17-DEC-2009
Filing Date:	11-OCT-2005
Time Stamp:	17:09:02
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$810
RAM confirmation Number	4244
Deposit Account	191970
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.20 (Post Issuance fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		AMENDwithRCE.pdf	232157 c7e9ebbc79906fa7182350604499aa9fe7b576e9	yes	4

Multipart Description/PDF files in .zip description

Document Description	Start	End
Amendment After Final	1	1
Claims	2	3
Applicant Arguments/Remarks Made in an Amendment	4	4

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
2	Request for Continued Examination (RCE)	RCE.pdf	697433 af669f212339d50f0ac6434138497baf16299a3e	no	3

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
3	Fee Worksheet (PTO-875)	fee-info.pdf	29818 8fc24dae60487e5945f726cc0c0a8e741fb6dd38	no	2

Warnings:

Information:

Total Files Size (in bytes): 959408

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re the Application of: Tzannes et al.	))	Group Art Unit: 2447
Application No.: 11/246,163	))	Examiner: Pfizenmayer, M.
Filed: October 11, 2005	))	Confirmation No.: 5478
Atty. File No.: 5550-54	))	

For: RESOURCE SHARING IN A TELECOMMUNICATIONS ENVIRONMENT

AMENDMENT AND RESPONSE

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Applicants submit this Amendment and Response to address the Final Office Action having a mailing date of December 9, 2009. Please credit any overpayment or charge any underpayment to Deposit Account No. 19-1970.

Please amend the above-identified patent application as follows:

Amendments to the Claims are shown in the listing of claims which begins on page 2 of this paper.

Remarks begin on page 4 of this paper.

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

1. – 45. (Cancelled)

46. (New) A method of allocating shared memory in a transceiver comprising:

transmitting or receiving, by the transceiver, a message during initialization indicating a maximum number of bytes of memory that can be allocated to an interleaver;

allocating, in the transceiver, a first number of bytes of a shared memory to an interleaver to interleave a first plurality of Reed Solomon (RS) coded data bytes for transmission at a first data rate; and

allocating, in the transceiver, a second number of bytes of the shared memory to a deinterleaver to deinterleave a second plurality RS coded data bytes received at a second data rate,

wherein the allocated memory for the interleaver does not exceed the maximum number of bytes indicated in the message, and

wherein the shared memory is used to simultaneously interleave the first plurality of RS coded data bytes and deinterleave the second plurality of RS coded data bytes.

47. (New) The method of claim 46, wherein the allocating is based on an impulse noise protection requirement.

48. (New) The method of claim 46, wherein the allocating is based on a latency requirement.

49. (New) The method of claim 46, wherein the allocating is based on a bit error rate requirement.

REMARKS

Applicants respectfully request reconsideration of this application as amended.

By this amendment, the pending claims have been cancelled without prejudice or disclaimer in favor of the newly presented claims.

Applicants would like to thank Examiners Pfizenmayer and Bruckhart for the courtesies extended during the December 8, 2009 Personal Interview and during the subsequent email exchanges. During the interview, the general operation of the invention was discussed and it was agreed that the proposed amendments to the claims "were a step in the right direction." The Examiner also suggested additional features for the claim.

By this amendment, new claim 46 is presented that more particularly claims certain aspects of the invention. The combination of features in claim 46 is neither taught nor suggested by the cited reference.

In that all objections are rejections are moot, and the pending claims are patentably distinguishable from the reference, a Notice of Allowance is earnestly solicited.

The Commissioner is hereby authorized to charge to deposit account number 19-1970 any fees under 37 CFR § 1.16 and 1.17 that may be required by this paper and to credit any overpayment to that Account. If any extension of time is required in connection with the filing of this paper and has not been separately requested, such extension is hereby petitioned.

Respectfully submitted,

SHERIDAN ROSS P.C.

Date: 17 Dec '09

By: ____________________

Jason H. Vick
Reg. No. 45,285
1560 Broadway, Suite 1200
Denver, Colorado 80202
Telephone: 303-863-9700

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number	Filing Date	
	11/246,163	10/11/2005	☐ To be Mailed

APPLICATION AS FILED – PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	SMALL ENTITY ☐ RATE ($)	FEE ($)	OR	OTHER THAN SMALL ENTITY RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =		OR	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =			X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $250 ($125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							
			TOTAL			TOTAL	

* If the difference in column 1 is less than zero, enter "0" in column 2.

APPLICATION AS AMENDED – PART II

AMENDMENT	12/17/2009	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE ($)	ADDITIONAL FEE ($)	OR	OTHER THAN SMALL ENTITY RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 4	Minus	** 45	= 0	X $ =		OR	X $52=	0
	Independent (37 CFR 1.16(h))	* 1	Minus	***5	= 0	X $ =		OR	X $220=	0
	☐ Application Size Fee (37 CFR 1.16(s))									
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	0

AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	RATE ($)	ADDITIONAL FEE ($)		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =		OR	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =		OR	X $ =	
	☐ Application Size Fee (37 CFR 1.16(s))									
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

Legal Instrument Examiner:
/Fennell A. Pearlie/

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
11/246,163	10/11/2005	Marcos C. Tzannes	5550-54	5478

62574 7590 12/16/2009

Jason H. Vick
Sheridan Ross, PC
Suite # 1200
1560 Broadway
Denver, CO 80202

EXAMINER	
PFIZENMAYER, MARK C	

ART UNIT	PAPER NUMBER
2447	

NOTIFICATION DATE	DELIVERY MODE
12/16/2009	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

jvick@sheridanross.com

PTOL-90A (Rev. 04/07)

Interview Summary	**Application No.** 11/246,163	**Applicant(s)** TZANNES ET AL.	
	Examiner BENJAMIN R. BRUCKART	**Art Unit** 2446	

All participants (applicant, applicant's representative, PTO personnel):

(1) *BENJAMIN R. BRUCKART*.

(2) *Pfizenmayer, Mark*.

(3) *Jason H Vick, Reg. No. 45, 285*.

(4) *Inventor Marcos Tzannes*.

Date of Interview: *08 December 2009*.

Type: a)☐ Telephonic b)☐ Video Conference
c)☒ Personal [copy given to: 1)☒ applicant 2)☐ applicant's representative]

Exhibit shown or demonstration conducted: d)☐ Yes e)☐ No.
If Yes, brief description: _____.

Claim(s) discussed: *1*.

Identification of prior art discussed: *N/A*.

Agreement with respect to the claims f)☐ was reached. g)☒ was not reached. h)☐ N/A.

Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments: *See Continuation Sheet*.

(A fuller description, if necessary, and a copy of the amendments which the examiner agreed would render the claims allowable, if available, must be attached. Also, where no copy of the amendments that would render the claims allowable is available, a summary thereof must be attached.)

THE FORMAL WRITTEN REPLY TO THE LAST OFFICE ACTION MUST INCLUDE THE SUBSTANCE OF THE INTERVIEW. (See MPEP Section 713.04). If a reply to the last Office action has already been filed, APPLICANT IS GIVEN A NON-EXTENDABLE PERIOD OF THE LONGER OF ONE MONTH OR THIRTY DAYS FROM THIS INTERVIEW DATE, OR THE MAILING DATE OF THIS INTERVIEW SUMMARY FORM, WHICHEVER IS LATER, TO FILE A STATEMENT OF THE SUBSTANCE OF THE INTERVIEW. See Summary of Record of Interview requirements on reverse side or on attached sheet.

/Benjamin R Bruckart/
Primary Examiner, Art Unit 2446

Summary of Record of Interview Requirements

Manual of Patent Examining Procedure (MPEP), Section 713.04, Substance of Interview Must be Made of Record
A complete written statement as to the substance of any face-to-face, video conference, or telephone interview with regard to an application must be made of record in the application whether or not an agreement with the examiner was reached at the interview.

Title 37 Code of Federal Regulations (CFR) § 1.133 Interviews
Paragraph (b)

In every instance where reconsideration is requested in view of an interview with an examiner, a complete written statement of the reasons presented at the interview as warranting favorable action must be filed by the applicant. An interview does not remove the necessity for reply to Office action as specified in §§ 1.111, 1.135. (35 U.S.C. 132)

37 CFR §1.2 Business to be transacted in writing.
All business with the Patent or Trademark Office should be transacted in writing. The personal attendance of applicants or their attorneys or agents at the Patent and Trademark Office is unnecessary. The action of the Patent and Trademark Office will be based exclusively on the written record in the Office. No attention will be paid to any alleged oral promise, stipulation, or understanding in relation to which there is disagreement or doubt.

The action of the Patent and Trademark Office cannot be based exclusively on the written record in the Office if that record is itself incomplete through the failure to record the substance of interviews.

It is the responsibility of the applicant or the attorney or agent to make the substance of an interview of record in the application file, unless the examiner indicates he or she will do so. It is the examiner's responsibility to see that such a record is made and to correct material inaccuracies which bear directly on the question of patentability.

Examiners must complete an Interview Summary Form for each interview held where a matter of substance has been discussed during the interview by checking the appropriate boxes and filling in the blanks. Discussions regarding only procedural matters, directed solely to restriction requirements for which interview recordation is otherwise provided for in Section 812.01 of the Manual of Patent Examining Procedure, or pointing out typographical errors or unreadable script in Office actions or the like, are excluded from the interview recordation procedures below. Where the substance of an interview is completely recorded in an Examiners Amendment, no separate Interview Summary Record is required.

The Interview Summary Form shall be given an appropriate Paper No., placed in the right hand portion of the file, and listed on the "Contents" section of the file wrapper. In a personal interview, a duplicate of the Form is given to the applicant (or attorney or agent) at the conclusion of the interview. In the case of a telephone or video-conference interview, the copy is mailed to the applicant's correspondence address either with or prior to the next official communication. If additional correspondence from the examiner is not likely before an allowance or if other circumstances dictate, the Form should be mailed promptly after the interview rather than with the next official communication.

The Form provides for recordation of the following information:
- Application Number (Series Code and Serial Number)
- Name of applicant
- Name of examiner
- Date of interview
- Type of interview (telephonic, video-conference, or personal)
- Name of participant(s) (applicant, attorney or agent, examiner, other PTO personnel, etc.)
- An indication whether or not an exhibit was shown or a demonstration conducted
- An identification of the specific prior art discussed
- An indication whether an agreement was reached and if so, a description of the general nature of the agreement (may be by attachment of a copy of amendments or claims agreed as being allowable). Note: Agreement as to allowability is tentative and does not restrict further action by the examiner to the contrary.
- The signature of the examiner who conducted the interview (if Form is not an attachment to a signed Office action)

It is desirable that the examiner orally remind the applicant of his or her obligation to record the substance of the interview of each case. It should be noted, however, that the Interview Summary Form will not normally be considered a complete and proper recordation of the interview unless it includes, or is supplemented by the applicant or the examiner to include, all of the applicable items required below concerning the substance of the interview.

A complete and proper recordation of the substance of any interview should include at least the following applicable items:
1) A brief description of the nature of any exhibit shown or any demonstration conducted,
2) an identification of the claims discussed,
3) an identification of the specific prior art discussed,
4) an identification of the principal proposed amendments of a substantive nature discussed, unless these are already described on the Interview Summary Form completed by the Examiner,
5) a brief identification of the general thrust of the principal arguments presented to the examiner,
   (The identification of arguments need not be lengthy or elaborate. A verbatim or highly detailed description of the arguments is not required. The identification of the arguments is sufficient if the general nature or thrust of the principal arguments made to the examiner can be understood in the context of the application file. Of course, the applicant may desire to emphasize and fully describe those arguments which he or she feels were or might be persuasive to the examiner.)
6) a general indication of any other pertinent matters discussed, and
7) if appropriate, the general results or outcome of the interview unless already described in the Interview Summary Form completed by the examiner.

Examiners are expected to carefully review the applicant's record of the substance of an interview. If the record is not complete and accurate, the examiner will give the applicant an extendable one month time period to correct the record.

Examiner to Check for Accuracy

If the claims are allowable for other reasons of record, the examiner should send a letter setting forth the examiner's version of the statement attributed to him or her. If the record is complete and accurate, the examiner should place the indication, "Interview Record OK" on the paper recording the substance of the interview along with the date and the examiner's initials.

Continuation of Substance of Interview including description of the general nature of what was agreed to if an agreement was reached, or any other comments: The examiner and applicant discussed an overview of the invention and explained features of simultaneous transfer and types of interleaving and allocation of memory based on direction of transmission and bandwidth. The examiner felt the proposed amendment was a step in the right direction but that more details would be recommended to overcome the cited prior art. The examiner suggested the features of need more detailing such as type of memory, type of interleaving to distinguish from the prior art or memory art. .

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re the Application of: Tzannes et al.	))	Group Art Unit: 2447
Application No.: 11/246,163	))	Examiner: LEUNG, Jack C.
Filed: October 11, 2005	))	Confirmation No.: 5478
Atty. File No.: 5550-54	))	

For: RESOURCE SHARING IN A TELECOMMUNICATIONS ENVIRONMENT

AMENDMENT AND RESPONSE

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

Applicants submit this Amendment and Response to address the Office Action having a mailing date of February 24, 2009. Please credit any overpayment or charge any underpayment to Deposit Account No. 19-1970.

Please amend the above-identified patent application as follows:

Amendments to the Specification begin on page 2 of this paper.

Amendments to the Claims are shown in the listing of claims which begins on page 3 of this paper.

Remarks begin on page 8 of this paper.

Amendments to the Specification:

Please amend the Specification as follows:

[0006] Accordingly, an exemplary aspect of this invention relates to sharing memory between one or more interleavers and/or ~~deinterlaevers~~ deinterleavers in a transceiver. More particularly, an exemplary aspect of this invention relates to shared latency path memory in a transceiver.

[00048] Example #1

A first transmitter portion or receiver portion latency path may carry data from a video application, which needs a very low BER but can tolerate higher latency. In this case, the video will be transported using an latency path that has a large amount of interleaving/deinterleaving and coding (also known as Forward Error Correction (FEC) coding). For example, the latency path may be configured with Reed-Solomon coding using a codeword size of 255 bytes (N=255) with 16 checkbytes (R=16) and interleaving/deinterleaving using an interleaver depth of 64 (D=64). This latency path will require ~~N*D=16*255=16Kbytes~~ N*D=255*64=16Kbytes of interleaver memory at the transmitter (or de-interleaver memory at the receiver). This latency path will be able to correct a burst of errors that is less than 512 bytes in duration.

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

1. (Original) A method for sharing resources in a transceiver comprising:

allocating a first portion of shared memory to a first latency path and allocating a second portion of the shared memory to a second latency path.

2. (Original) The method of claim 1, wherein the first latency path includes an interleaver and the second latency path includes an interleaver.

3. (Original) The method of claim 1, wherein the first latency path includes an interleaver and the second latency path includes a deinterleaver.

4. (Original) The method of claim 1, wherein the first latency path includes a deinterleaver and the second latency path includes a deinterleaver.

5. (Original) The method of claim 1, further comprising transmitting to another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

6. (Original) The method of claim 1, further comprising receiving from another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

7. (Original) The method of claim 1, further comprising allocating a shared processing module to a plurality of coding and/or decoding modules.

8. (Original) The method of claim 1, wherein the allocating of at least one portion of the shared memory is based on one or more communication parameters.

9. (Original) The method of claim 8, wherein at least one of the communication parameters is a data rate, a latency, an INP value or a bit error rate (BER).

10. (Original) A transceiver comprising:

a first portion of shared memory that is allocated to a first latency path; and

a second portion of the shared memory that is allocated to a second latency path.

11. (Original) The transceiver of claim 10, further comprising:

an allocation module designed to allocate the shared memory based on one or more communication parameters.

12. (Original) The transceiver of claim 11, wherein at least one of the communication parameters is a data rate, a latency, an INP value or a Bit Error Rate (BER).

13. (Original) The transceiver of claim 10, wherein the first latency path includes an interleaver and the second latency path includes an interleaver.

14. (Original) The transceiver of claim 10, wherein the first latency path includes an interleaver and the second latency path includes a deinterleaver.

15. (Original) The transceiver of claim 10, wherein the first latency path includes a deinterleaver and the second latency path includes a deinterleaver.

16. (Original) The transceiver of claim 10, further comprising a shared resource management module designed to determine information that is transmitted to another transceiver, wherein the information is used to determine a maximum amount of shared memory that can be allocated.

17. (Original) The transceiver of claim 10, further comprising a shared resource management module designed to utilize information that is received from another transceiver, wherein the information is used to determine a maximum amount of shared memory that can be allocated.

18. (Original) The transceiver of claim 10, further comprising a shared processing module designed to provide processing resources to a plurality of coding and/or decoding modules.

19. (Currently Amended) A system for sharing resources, such as memory, in a transceiver comprising:

means for allocating a first portion of a shared memory to a first latency path and means for allocating a second portion of the shared memory to a second latency path.

20. (Original) The system of claim 19, wherein the first latency path includes an interleaver and the second latency path includes an interleaver.

21. (Original) The system of claim 19, wherein the first latency path includes an interleaver and the second latency path includes a deinterleaver.

22. (Original) The system of claim 19, wherein the first latency path includes a deinterleaver and the second latency path includes a deinterleaver.

23. (Original) The system of claim 19, further comprising means for transmitting to another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

24. (Original) The system of claim 19, further comprising means for receiving from another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

25. (Original) The system of claim 19, further comprising means for allocating a shared processing module to a plurality of coding and/or decoding modules.

26. (Original) The system of claim 19, wherein the allocating of at least one portion of the shared memory is based on one or more communication parameters.

27. (Original) The system of claim 26, wherein at least one of the communication parameters is a data rate, a latency, an INP value or a bit error rate (BER).

28. (Currently Amended) A protocol for sharing resources~~, such as memory,~~ in a transceiver comprising:

allocating a first portion of a shared memory to a first latency path and allocating a second portion of the shared memory to a second latency path.

29. (Original) The protocol of claim 28, wherein the first latency path includes an interleaver and the second latency path includes an interleaver.

30. (Original) The protocol of claim 28, wherein the first latency path includes an interleaver and the second latency path includes a deinterleaver.

31. (Original) The protocol of claim 28, wherein the first latency path includes a deinterleaver and the second latency path includes a deinterleaver.

32. (Original) The protocol of claim 28, further comprising transmitting to another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

33. (Original) The protocol of claim 28, further comprising receiving from another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

34. (Original) The protocol of claim 28, further comprising allocating a shared processing module to a plurality of coding and/or decoding modules.

35. (Original) The protocol of claim 28, wherein the allocating of at least one portion of the shared memory is based on one or more communication parameters.

36. (Original) The protocol of claim 35, wherein at least one of the communication parameters is a data rate, a latency, an INP value or a bit error rate (BER).

37. (Original) An information storage media having stored thereon information that when executed allows sharing of resources in a transceiver comprising:

information that allocates a first portion of shared memory to a first latency path and information that allocates a second portion of the shared memory to a second latency path.

38. (Original) The media of claim 37, wherein the first latency path includes an interleaver and the second latency path includes an interleaver.

39. (Original) The media of claim 37, wherein the first latency path includes an interleaver and the second latency path includes a deinterleaver.

40. (Original) The media of claim 37, wherein the first latency path includes a deinterleaver and the second latency path includes a deinterleaver.

41. (Original) The media of claim 37, further comprising information that transmits to another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

42. (Original) The media of claim 37, further comprising information that receives from another transceiver information that is used to determine a maximum amount of shared memory that can be allocated.

43. (Original) The media of claim 37, further comprising information that allocates a shared processing module to a plurality of coding and/or decoding modules.

44. (Original) The media of claim 37, wherein the allocating of at least one portion of the shared memory is based on one or more communication parameters.

45. (Original) The media of claim 44, wherein at least one of the communication parameters is a data rate, a latency, an INP value or a bit error rate (BER).

REMARKS

Applicant respectfully requests reconsideration of this application as amended.

By this amendment, the outstanding objections have been addressed in accordance with the Examiner's recommendations.

Additionally, the 35 U.S.C. §101 rejections have been addressed and it is believed the rejected claims are in compliance therewith.

Regarding the art-based rejections, Fadavi-Ardekani states that "a simple of a transmit interleaver for standard ADSL requires 16 Kbytes per session for downstream processing and 2 Kbytes per session for upstream processing." Fadavi-Ardekani then states that "the invention utilizes the same memory for receive data and transmit data and thus requires 20 Kbytes to support a standard ADSL session at full interleave depth…"

MPEP 2121.01 states that "In determining that quantum of prior art disclosure which is necessary to declare an applicant's invention 'not novel' or 'anticipated' within section 102, the stated test is whether a reference contains an 'enabling disclosure'... ." In re Hoeksema, 399 F.2d 269, 158 USPQ 596 (CCPA 1968). The disclosure in an assertedly anticipating reference must provide an enabling disclosure of the desired subject matter; mere naming or description of the subject matter is insufficient, if it cannot be produced without undue experimentation. Elan Pharm., Inc. v. **>Mayo Found. For Med. Educ. & Research<, 346 F.3d 1051, 1054, 68 USPQ2d 1373, 1376 (Fed. Cir. 2003).

Applicants respectfully submit Fadavi-Ardekani is not enabling for how the same memory can be used for simultaneous receiving of data and transmitting of data.

In that Fadavi-Ardekani is not enabling, Applicants respectfully submit Fadavi-Ardekani is not anticipatory of the claimed subject matter.

Applicants therefore respectfully submit the application is patentably distinguishable from the cited reference and respectfully request a Notice of Allowance.

As discussed with SPE James Joon Hwang, the Examiner assigned to examining this application is respectfully requested to contact the undersigned to schedule a Personal Interview to discuss the merits of the application. As also discussed, the next Office Action, if not a Notice of Allowance, will not be made final.

The Commissioner is hereby authorized to charge to deposit account number 19-1970 any fees under 37 CFR § 1.16 and 1.17 that may be required by this paper and to credit any overpayment to that Account. If any extension of time is required in connection with the filing of this paper and has not been separately requested, such extension is hereby petitioned.

Respectfully submitted,

SHERIDAN ROSS P.C.

Date: 21 Aug 09

By: ______________________

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Denver, Colorado 80202
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PTO/SB/22 (07-09)
Approved for use through 07/31/2012. OMB 0651-0031
U.S. Patent and Trademark Office; U.S. DEPARMENT OF COMMERCE
Under the paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

PETITION FOR EXTENSION OF TIME UNDER 37 CFR 1.136(a) FY 2009 *(Fees pursuant to the Consolidated Appropriations Act, 2005 (H.R. 4818).)*	Docket Number (Optional) 5550-54
Application Number 11/246,163	Filed October 11, 2005
For RESOURCE SHARING IN A TELECOMMUNICATIONS ENVIRONMENT	
Art Unit 2447	Examiner LEUNG, Jack C.

This is a request under the provisions of 37 CFR 1.136(a) to extend the period for filing a reply in the above identified application.

The requested extension and fee are as follows (check time period desired and enter the appropriate fee below):

	Fee	Small Entity Fee	
☐ One month (37 CFR 1.17(a)(1))	$130	$65	$
☐ Two months (37 CFR 1.17(a)(2))	$490	$245	$
☑ Three months (37 CFR 1.17(a)(3))	$1110	$555	$ 1110
☐ Four months (37 CFR 1.17(a)(4))	$1730	$865	$
☐ Five months (37 CFR 1.17(a)(5))	$2350	$1175	$

☐ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check in the amount of the fee is enclosed.

☐ Payment by credit card. Form PTO-2038 is attached.

☑ The Director has already been authorized to charge fees in this application to a Deposit Account.

☑ The Director is hereby authorized to charge any fees which may be required, or credit any overpayment, to Deposit Account Number 19-1970.

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

I am the ☐ applicant/inventor.

☐ assignee of record of the entire interest. See 37 CFR 3.71.
Statement under 37 CFR 3.73(b) is enclosed (Form PTO/SB/96).

☑ attorney or agent of record. Registration Number 45,285

☐ attorney or agent under 37 CFR 1.34.
Registration number if acting under 37 CFR 1.34 ______

Signature: [signature] Date: 21 Aug '09

Typed or printed name: Jason H. Vick Telephone Number: 303-863-9700

NOTE: Signatures of all the inventors or assignees of record of the entire interest or their representative(s) are required. Submit multiple forms if more than one signature is required, see below.

☑ Total of 1 forms are submitted.

Electronic Patent Application Fee Transmittal

Application Number:	11246163
Filing Date:	11-Oct-2005
Title of Invention:	Resource sharing in a telecommunications environment
First Named Inventor/Applicant Name:	Marcos C. Tzannes
Filer:	Jason Vick/Joanne Vos
Attorney Docket Number:	5550-54

Filed as Large Entity

Utility under 35 USC 111(a) Filing Fees

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Extension - 3 months with $0 paid	1253	1	1110	1110

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Miscellaneous:				
		Total in USD ($)		**1110**

Electronic Acknowledgement Receipt	
EFS ID:	5933059
Application Number:	11246163
International Application Number:	
Confirmation Number:	5478
Title of Invention:	Resource sharing in a telecommunications environment
First Named Inventor/Applicant Name:	Marcos C. Tzannes
Customer Number:	62574
Filer:	Jason Vick/Joanne Vos
Filer Authorized By:	Jason Vick
Attorney Docket Number:	5550-54
Receipt Date:	21-AUG-2009
Filing Date:	11-OCT-2005
Time Stamp:	16:28:15
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	$1110
RAM confirmation Number	1808
Deposit Account	191970
Authorized User	

The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows:

Charge any Additional Fees required under 37 C.F.R. Section 1.16 (National application filing, search, and examination fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.17 (Patent application and reexamination processing fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.19 (Document supply fees)

Charge any Additional Fees required under 37 C.F.R. Section 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		F20090821_AMEND_01.pdf	695796 4d49448b80cf218ad13da53773621234bee98ce3	yes	9

Multipart Description/PDF files in .zip description

Document Description	Start	End
Amendment/Req. Reconsideration-After Non-Final Reject	1	1
Specification	2	2
Claims	3	7
Applicant Arguments/Remarks Made in an Amendment	8	9

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
2	Extension of Time	F20090821_EOT_01.pdf	121899 d5d846a10f04906c3859631fb789bda9566d51da	no	1

Warnings:

Information:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
3	Fee Worksheet (PTO-875)	fee-info.pdf	29699 f37dcea9c75328cca3e5f322d94dc8bad113b84c	no	2

Warnings:

Information:

Total Files Size (in bytes): 847394

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 11/246,163	Filing Date 10/11/2005	☐ To be Mailed

APPLICATION AS FILED – PART I

FOR	NUMBER FILED (Column 1)	NUMBER EXTRA (Column 2)	SMALL ENTITY ☐ RATE ($)	SMALL ENTITY FEE ($)		OTHER THAN SMALL ENTITY RATE ($)	OTHER THAN SMALL ENTITY FEE ($)
☒ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A			N/A	300
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A			N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A			N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*	X $ =		OR	X $ =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*	X $ =		OR	X $ =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $250 ($125 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).						
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))							
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL			TOTAL	300

APPLICATION AS AMENDED – PART II

AMENDMENT	08/21/2009	CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	SMALL ENTITY RATE ($)	ADDITIONAL FEE ($)		OTHER THAN SMALL ENTITY RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 45	Minus	** 45	= 0	X $ =		OR	X $52=	0
	Independent (37 CFR 1.16(h))	* 5	Minus	***5	= 0	X $ =		OR	X $220=	0
	☐ Application Size Fee (37 CFR 1.16(s))									
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	0

AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT (Column 1)		HIGHEST NUMBER PREVIOUSLY PAID FOR (Column 2)	PRESENT EXTRA (Column 3)	RATE ($)	ADDITIONAL FEE ($)		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=	X $ =		OR	X $ =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=	X $ =		OR	X $ =	
	☐ Application Size Fee (37 CFR 1.16(s))									
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
						TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

Legal Instrument Examiner:
/GWENDOLYN MYERS/

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

TQ DELTA, LLC, Plaintiff, v. 2WIRE, INC., Defendant.	C.A. No. 1: 13-cv-1835-RGA
TQ DELTA, LLC, Plaintiff, v. ZHONE TECHNOLOGIES, INC, Defendants.	C.A. No. 1:13-cv-1836-RGA
TQ DELTA, LLC, Plaintiff, v. ZYXEL COMMUNICATIONS, INC. and ZYXEL COMMUNICATIONS CORPORATION Defendants.	C.A. No. 1: 13-cv-2013-RGA
TQ DELTA, LLC, Plaintiff, v. ADTRAN, INC., Defendants.	C.A. No. 1: 14-cv-954-RGA